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PRELIMINARY CANDIDATE ADVANCED AVIONICS SYSTEM (PCAAS) FINAL REPORT

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16. Abstract

The Preliminary Candidate Advanced Avionics System (PCAAS) for general aviation implements all avionics functions including flight management, navigation, communication, surveillance, automatic flight control, engine health management, flight status correlation, and displays and controls. These functions provide a significant increase in safety and utility for a single pilot GA aircraft operating IFR in the current or upgraded ATC environment. The implementation of the avionic functions uses many off the shelf avionics end items such as radios, transponders, weather radar, etc., which are integrated into PCAAS using a distributed processor microcomputer referred to as the Microcomputer Control Complex (MCC). Many sophisticated computations are performed in the MCC to provide such aids to the pilot as flight planning, fuel status, area navigation, checklist presentation, integrated data control, frequency management, engine management and diagnostics, orientation relative to navigation aids and airports, and automatic flight control including RNAV steering and approach coupling.

The report includes specifications which define the system functional requirements, the subsystem and interface requirements, and other requirements such as maintainability, modularity, and reliability. Design definition of all required avionics functions and a system risk analysis are presented.

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FOREWORD

This report presents the results of a study of a Preliminary Candidate Advanced Avionics System for general aviation accomplished for the National Aeronautics and Space Administration under Contract NAS2-9311. The NASA Technical Monitor was George P. Callas.

For the convenience of the reader the main body of the report is preceded by an overall summary.

The authors gratefully acknowledge the fine work of the Systems Technology, Inc., Publications Department in the preparation of this report.

TABLE OF CONTENTS

PRELIMINARY CANDIDATE ADVANCED AVIONICS SYSTEM (PCAAS)
FINAL REPORT

Gary L. Teper and Roger H. Hoh
Systems Technology, Inc.

Richard K. Smyth
Milco International, Inc.

SUMMARY

Background

The Preliminary Candidate Advanced Avionics System (PCAAS) is one important element of the National Aeronautics and Space Administration's General Aviation Advanced Avionics System Technology Program. The PCAAS program was initiated in July 1976; it was preceded by a NASA-sponsored workshop on General Aviation Avionics conducted in November 1975. Two additional program elements served as inputs to the PCAAS program — namely, the Computer Technology Forecast for General Aviation and the Forecast of the Air Traffic Control Environment for General Aviation in the 1980's. The final reports from both of these studies were available in June 1976.

These NASA/OAST supported studies are responsive to the nation's need for reasonably priced general aviation avionics to make general aviation aircraft travel more useful and practical for more people.

Scope of Study

Preliminary and final systems requirements specifications were prepared which defined the functional requirements, the subsystem requirements, the interface requirements, and other requirements such as software, maintainability, modularity, and reliability. The scope of the PCAAS study included the design definition of all required avionics functions such as Navigation, Flight Control, Engine Management, ATC Surveillance, Flight Management, Communications, and the Pilot Controls and Displays.

A risk assessment was performed which examined three categories of risk: that national or international systems are not implemented; that PCAAS mechanization techniques would prove unsatisfactory; and that the component technology would be unavailable.

The study included the preparation of a design report which described the tradeoffs performed and the selections made to arrive at the PCAAS design. The resulting PCAAS design included the selection of off-the-shelf avionics to be integrated with PCAAS-unique elements including new pilot displays and controls and Microcomputer Control Complex (MCC). A distributed system architecture was derived to permit system modularity. A mechanization of the MCC using off-the-shelf circuit modules was formulated. The design is sufficiently detailed to provide the basis for the next phase of the NASA General Aviation Avionics program.

The study did not include a detailed description of the algorithms to be implemented by the MCC. However, the functional description is sufficiently detailed that the algorithms would be straightforward to develop.

Basic Objectives

The basic objective of PCAAS is to permit safe single pilot IFR (instrument flight rules) flight within the current or updated ATC (air traffic control) environment. It is expected that the PCAAS design will utilize advanced technology to obtain the required capability at an affordable cost and with acceptable reliability.

This basic objective is supported by a number of design guidelines which include the following:

- The Advanced Avionics System should result in a significant reduction in single pilot workload during IFR flight.
- A significant increase in capability must be achieved without adding significant cost or reducing reliability.
- The system architecture should provide modularity to permit: transition from current avionics systems to the advanced system; addition or deletion of functions for

the wide spectrum of general aviation aircraft: and addition of functions to adapt to the upgraded ATC environment.

- The Advanced Avionics System should represent a major departure from current system design and architecture which integrates all avionics functions through digital processing.

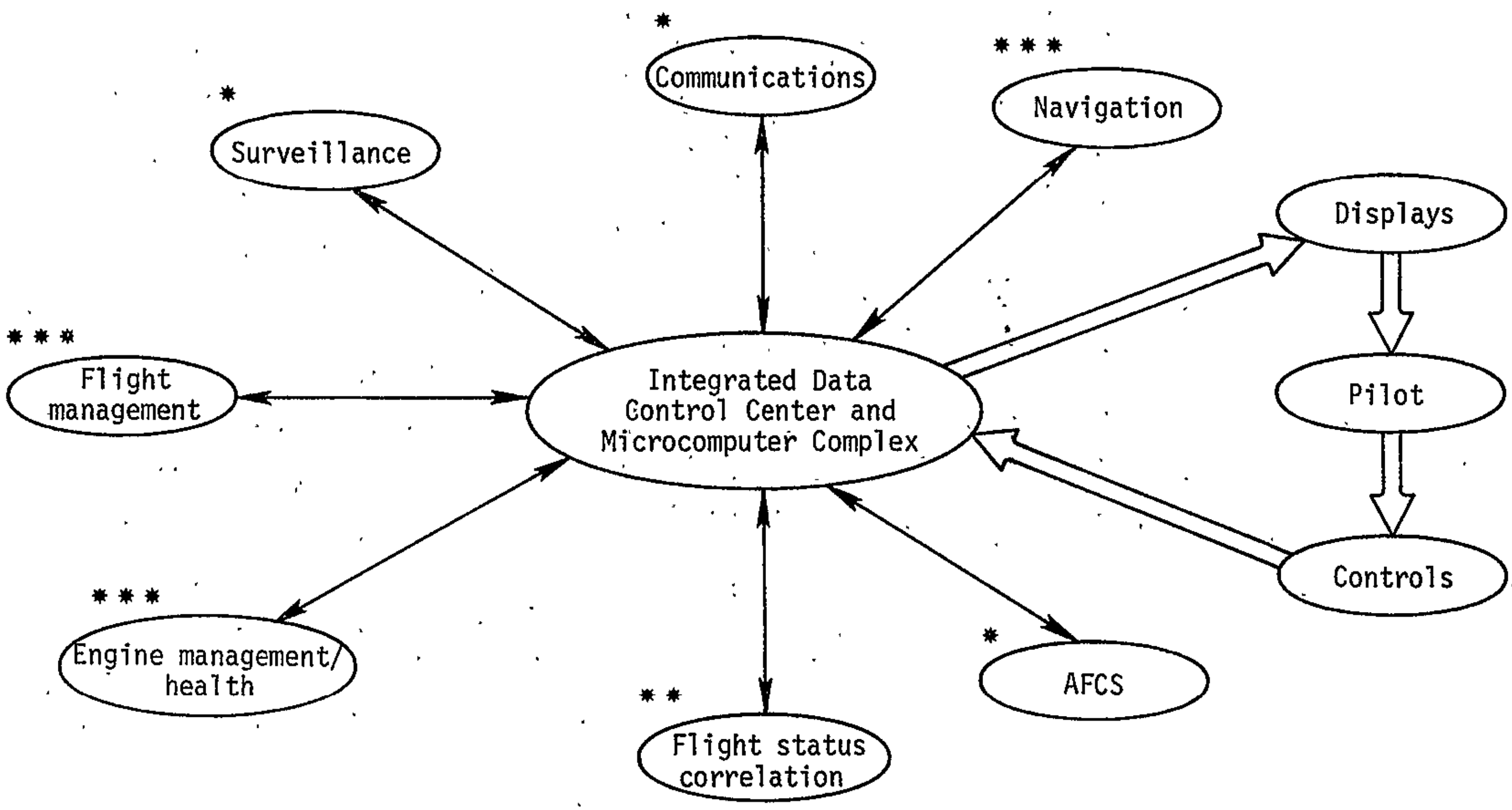
System Design Philosophy

The underlying motivation for the design of an advanced avionics system is to enhance safety by reducing the pilot workload. Improvements in displays and controls on currently existing systems would reduce workload, but not by the order of magnitude required to operate a complex aircraft in high density terminal areas with one pilot. A system design philosophy was adopted to achieve significant workload relief through the use of modern digital technology to perform part or all of the functions normally accomplished by a second pilot. This resulted in two basic display and control system elements: the Integrated Data Control Center (IDCC), and the Navigation Map Display (NMD). A Microcomputer Control Complex is provided to accomplish the required computations. These elements and their specific functions are described in subsequent sections of the report.

The IDCC and NMD were integrated with current state of the art instrument displays on the panel. New and revolutionary displays were not considered because of their high risk nature. It is felt that separate research programs should be undertaken to evaluate such (new) displays before they are incorporated into an Advanced Avionics System.

Summary of PCAAS Functions

This subsection contains a summary of the functions which comprise the PCAAS. A more detailed description of each of the functions is given in the section entitled "Functional Description." The PCAAS functions are shown schematically in Fig. 1. This figure indicates that each function interfaces directly with the Integrated Data Control Center (IDCC). Data are transferred from the IDCC and Microcomputer Control Complex (via the



Note: Stars above functions indicate their relative contribution to workload reduction.

Figure 1. PCAAS Function Summary

displays) to the pilot, who in turn can request information via the controls. The single line arrows in Fig. 1 indicate system mechanization, whereas the broad arrows indicate interfaces with the pilot via the displays and controls. The stars shown above each function represent the estimated relative contribution of that function to the overall workload reduction achieved by the PCAAS. Items with only one star (Surveillance Communication and AFCS) indicate that these items are relatively independent of the PCAAS. For example, the automatic flight control system already represents a major reduction in pilot workload. The additional reduction in pilot workload of this system with the addition of the PCAAS is not expected to be of major consequence. The same thing is true regarding communications and surveillance functions. On the other hand, the flight management and engine management/health functions either do not exist or are primitive in current aircraft. It is therefore expected that the addition of the PCAAS will allow major reductions in pilot workload via these functions. It is also expected that the PCAAS will result in major workload reductions via the navigation function (Navigation Map Display). Integration of these functions with the IDCC will allow the pilot to request and obtain such critical items as a continuous update of fuel reserves at the planned destinations or at selected alternates. The flight status correlation function will provide workload relief by performing cross-checks between various aircraft systems. An example of flight status correlation would be the checking of one VOR receiver against the other on a continuous basis. The Integrated Data Control Center will display information to the pilot via a dedicated CRT surface. The pilot/system interface will be accomplished using question and answer prompting, thereby minimizing the need for the pilot to learn special-purpose code names and instructions. A brief description of some of the primary functions is given in the following paragraphs.

Navigation.-Most of the calculations to be performed in the navigation function are not new and are representative of current generation area navigation systems. However, the transformation of processed navigation data into a Navigation Map Display (NMD), at costs consistent with general aviation budgets, is felt to be a significant contribution towards reducing the pilot's workload. Integration of the NMD with the Integrated Data Control

Center (IDCC) will allow the pilot to key in route structures based on VOR, airport, and airway labels as they appear on the IFR Charts. The corresponding latitude and longitude entries corresponding to the selected route structure waypoints are available from the data base stored in the MCC Mass Memory. If VHF uplink becomes available, the PCAAS will be capable of accepting and displaying ATC clearances on the IDCC CRT surface as well as on the NMD.

Flight management.-The PCAAS flight management function represents a significant increase in capability over current general aviation avionic systems which are primarily area navigation systems with some additional aids such as checklists. A summary of the features of the flight management system is given below.

- Aircraft performance:
  1. Displays takeoff and landing performance as a function of aircraft weight, altitude, and temperature. These parameters do not require pilot entry as they are measured or computed by PCAAS.
  2. Computes and displays maximum performance speeds.
- Fuel management:
  1. Computes fuel used and remaining.
  2. Continuous update of fuel reserves at destination or selected alternates based on current winds as computed by the navigation system.
- En route calculations:
  1. Computes climb or descent rate required to cross a specified fix at a specified altitude.
  2. Computes range at current or selected power settings.
  3. Computes altitude and power settings for maximum range or endurance.
- Weight and balance calculations:
  1. Pilot inputs weights and PCAAS computes point in loading envelope.
  2. Provides continuous update of weight and balance as fuel burns off.

Engine management and health monitoring.-The engine management and health monitoring function provides the pilot with valuable, timely information relative to his power plant which is usually not available or difficult to derive from engine handbook curves and tables. It is expected that a significant reduction in pilot workload will result from the "mixture flight director" which will allow the pilot to lean with minimum attention during all phases of flight. This flight director will be based on EGT, fuel flow, manifold pressure and rpm, and will account for the engine manufacturer's specifications and recommendations.

The engine management system will compute the manifold pressure and mixture setting for any pilot selected horsepower, at a given engine rpm. The true airspeed (TAS), miles per gallon, and gallons per hour will be computed for the selected power setting at the current altitude and outside air temperature.

The engine health system will display items on the IDCC CRT which may lead to an impending failure. An example of this would be excessive power settings for the current mixture setting such as might occur on a missed approach or balked landing climb.

Other PCAAS functions.-The communications, surveillance, and automatic flight control system (AFCS) functions are also included in PCAAS. The improvement in these functions over current technology is not expected to result in major reductions in pilot workload. However, a VHF data link, if it is implemented by the FAA, would reduce the pilot workload for routine communications and for ATC clearances. The lack of a VHF data link is felt to be a serious obstruction to the primary PCAAS objective of reducing pilot workload in the communications function.

Spectrum of Avionics

The spectrum of avionics functions and capabilities provided by PCAAS is represented by three design points for the three selected categories of general aviation aircraft:

- The Basic system corresponds to the advanced avionics for the simple, fixed gear, single engine aircraft.

- The Intermediate system corresponds to the advanced avionics for the well equipped, retractable gear, single engine aircraft and the light twin.

- The Upgrade system corresponds to the advanced avionics for the heavy twin and light business jet.

Emphasis has been placed on the Intermediate system during the PCAAS design study.

The planned modular buildup of the IDCC functions for the Basic, Intermediate, and Upgrade systems is summarized in Table 1.

The physical characteristics and cost are summarized for the PCAAS spectrum of elements for the three categories of systems in Table 2. The parameters presented in Table 2 include the system elements arranged vertically in the matrix, with the quantity per system, weight, power, and cost arranged horizontally for each of the three categories.

The PCAAS consists of a large number of off-the-shelf avionics and sensors. The PCAAS functional capability is integrated by means of the "new PCAAS" elements which are highlighted with boxes in Table 2. The Intermediate system "new PCAAS" elements include a 7 processor Microcomputer Control Complex (MCC), Status Discretes, Integrated Data Control Center (IDCC), and Navigation Map Display (NMD). In addition to these new elements PCAAS includes a number of sensors such as outside air temperature (OAT), indicated airspeed (IAS), manifold pressure (MP), etc., whose electrical outputs are digitized and used in various functional computations within the PCAAS. The total estimated cost of the Intermediate system is $45,295, of which $11,900 is for "new PCAAS" elements.

The vast majority of general aviation aircraft fall within the Basic category. A number of off-the-shelf items were deleted from the Intermediate system to arrive at the Basic system. Dual NAV/COMM radios were selected to provide dual VOR/LOC and Dual 720 channel communication. No DME, ADF, OMEGA or Glide Slope are provided in order to reduce cost. The RNAV function would be provided by dead reckoning updated with dual VOR position fixing.

TABLE 1. IDCC FUNCTIONS FOR BASIC, INTERMEDIATE, AND UPGRADE SYSTEMS

IDCC FUNCTIONS	LEVEL OF MODULAR BUILDUP OF IDCC		
	BASIC	INTERMEDIATE	UPGRADE
<u>FLIGHT MANAGEMENT</u>			
● Flight planning			
— Enter route data via VORs and airports or LAT-LONG	×	×	×
— Display fuel required, ETE, reserves	×	×	×
● Fuel management	×	×	×
● Speeds for best performance			×
● Optimum climb descent profiles			×
● Weight and balance			×
● Takeoff and landing performance			×
● Cruise calculations		×	×
<u>ENGINE MANAGEMENT</u>			
● MP and mixture flight director			
— Based on desired horsepower	×	×	×
— Based on desired TAS, mpg, gph			×
— Based on maximum endurance on range			×
● Display standard power setting data (MAP and rpm for given horsepower and altitude, etc.)	×	×	×
<u>ENGINE HEALTH</u>			
● Display items leading to impending failure — flash on and off	×	×	×
● Display status on request		×	×
● Display past trends for analysis by engine shop			×
<u>NAVIGATION</u>			
● Navigation map display		×	×
● Position display $\rho\theta$ or $\rho\rho$ from selected navaids or display LAT-LONG — display glide slope and wind	×	×	×
● Auto tune — automatically tune best navaids to fix position on NMD		×	×
● Status — display what navaids are tuned and estimated errors		×	×
● Compute ETA			
— Point selected on keyboard	×	×	×
— Point selected from range cursor on NMD		×	×
<u>CHECKLIST</u>			
● Routine checklists as requested from keyboard	×	×	×
● Automatically displayed emergency checklists	×	×	×
<u>FLIGHT STATUS CORRELATION</u>			
● Navigation signals — compare VOR-VOR; VOR-DME; LOC-LOC, GS-OM		×	×
● Instrument crosschecks			×
<u>STATUS OVERRIDE</u>			
(Engine problem or emergency checklist)	×	×	×
<u>NEAREST ALTERNATE</u>		×	×
<u>SELECT MAP MODES</u>		×	×

TABLE 2. PCAAS PHYSICAL CHARACTERISTICS AND COSTS

SYSTEM ELEMENT	BASIC SYSTEM QTY	WT	PWR	COST	INTERMEDIATE SYSTEM QTY	WT	PWR	COST	UPGRADE SYSTEM QTY	WT	PWR	COST
NAV RADIO #1	2[1]	19.6	24.0	2,000	1	3.7	11.2	1,400				
NAV RADIO #2[2]					1	3.3	12.0	1,700	2	6.6	24.0	3,400
DME					1	9.3	24.0	4,200	2	18.6	48.0	8,400
ADF					1	6.8	5.5	1,500	2	13.6	11.0	3,000
OMEGA NEW PCAAS					1	17.2	24.5	6,000	1	20.0	28.0	6,000
COMM RADIO					2	6.6	67.8	2,000	2	6.6	67.8	2,000
TRANSPONDER	1	3.0	14.0	600	1	3.0	14.0	600	2	6.0	28.0	1,200
WEATHER RADAR					1	20.0	68.8	5,500	1	14.9	98.0	7,100
RADAR ALTIMETER					1	2.5	8.4	1,000	1	4.5	15.1	2,300
ELT	1	3.0	-0-	125	1	3.0	-0-	125	1	3.0	-0-	125
ALTITUDE DIGITIZER	1	1.8	4.2	550	1	1.8	4.2	550	1	1.8	4.2	550
TAS SENSOR	1	0.6	0.1	90	1	0.6	0.1	90	1	0.6	0.1	90
PRESS ALT SENSOR	1	0.6	0.1	80	1	0.6	0.1	80	1	0.6	0.1	80
OAT SENSOR	1	0.3	0.1	30	1	0.3	0.1	30	1	0.3	0.1	30
MP SENSOR					2	1.6	0.2	170	2	1.6	0.2	170
FUEL FLOW RATE SENSOR	1	0.8	-0-	125	2	1.6	-0-	250	2	1.6	-0-	250
EGT SENSORS	1	0.1	0.1	125	8	1.0	0.1	1,000	8	1.0	0.1	1,000
DIR GYRO	1	4.0	15.0	2,300	1	5.4	20.0	3,000	2	10.8	40.0	6,000
ADI	1[3]	2.0	-0-	1,200	1	5.4	10.0	2,600	2	10.8	20.0	5,200
YAW RATE GYRO					1	1.8	2.0	300	1	1.9	2.0	300
MCC NEW PCAAS	1	8.3	40	2,900	1	20.8	100	8,775	1	20.8	110	9,700
STATUS DISCRETES NEW PCAAS					5	1.0	0.5	300	10	2.0	1.0	600
TAPE CARTRIDGE NEW PCAAS					1	3.0	49.5	300	1	3.0	49.5	300
IDCC NEW PCAAS	1	9.1	17.5	2,000	1	9.1	17.5	2,000	1	9.1	17.5	2,000
NAV MAP DISPLAY NEW PCAAS					1	9.0	16.0	2,000	1	9.0	16.0	2,000
AFCS ACTUATORS	1	9.0	25	750	2	18.0	50.0	1,500	3	12.0	75.0	2,250
MISC	1 lot	8.0	4.0	400	1 lot	20.0	10.0	1,000	1 lot	40.0	20.0	2,000
PCAAS TOTAL		70.2#	144.1W	$13,275		176#	516W	49,570		220.6#	890W	$66,045
NEW PCAAS TOTAL		17.4#	57.5W	$4,900		49.7#	208W	$17,900		63.9#	222W	$20,600

1. NAV/COMM FUNCTION
2. INCLUDES GS RCVR
3. VERTICAL GYRO

The weather radar and radar altimeter are deleted to reduce cost. The Basic system must depend upon ATC advisories to avoid weather cells. The "new PCAAS" elements for the Basic system include a three-processor MCC and IDCC but no moving map. The total estimated cost for the Basic system is $13,275, of which $4,900 is for "new PCAAS" elements.

The Upgrade system utilizes more hardware redundancy than does the Intermediate system, which is the primary reason for its greater cost. The Upgrade system includes dual glide slope, DME, ADF, transponders, directional gyros, and ADI, and three autopilot actuators (a rudder actuator is added). This additional redundant equipment amounts to $9,300 additional cost relative to the Intermediate system. The Upgrade system utilizes ugraded equipment for the weather radar, radar altimeter, and MCC with more memory for added functions. This upgraded equipment adds an increased cost of $4,300. The total estimated cost for the Upgrade system is $62,645, of which $13,300 is for "new PCAAS" elements.

The off-the-shelf avionics for the Intermediate system were selected on the basis of the lowest cost element which provided the required function with a few exceptions where the lowest cost element was unreliable or technically obsolete.

Displays

The key elements of the PCAAS consist of a Navigation Map Display, Fig. 2, and the Integrated Data Control Center, Fig. 3, which are located in prominent locations on the instrument panel.

The Navigation Map Display has a number of modes including en route display with detail, as shown in Fig. 2, or decluttered in which only the major features for the flight route are shown. Other modes include an approach mode which shows both the approach plate plan view as well as the glide slope cross section. The aircraft symbol is shown on the map and moves relative to the background. The map switches when the boundary of the map is approached. The map is "heading up" within the nearest octant (45 deg). The map symbologies are stored on the data cartridge mass memory and called up to the MCC working memory as required.

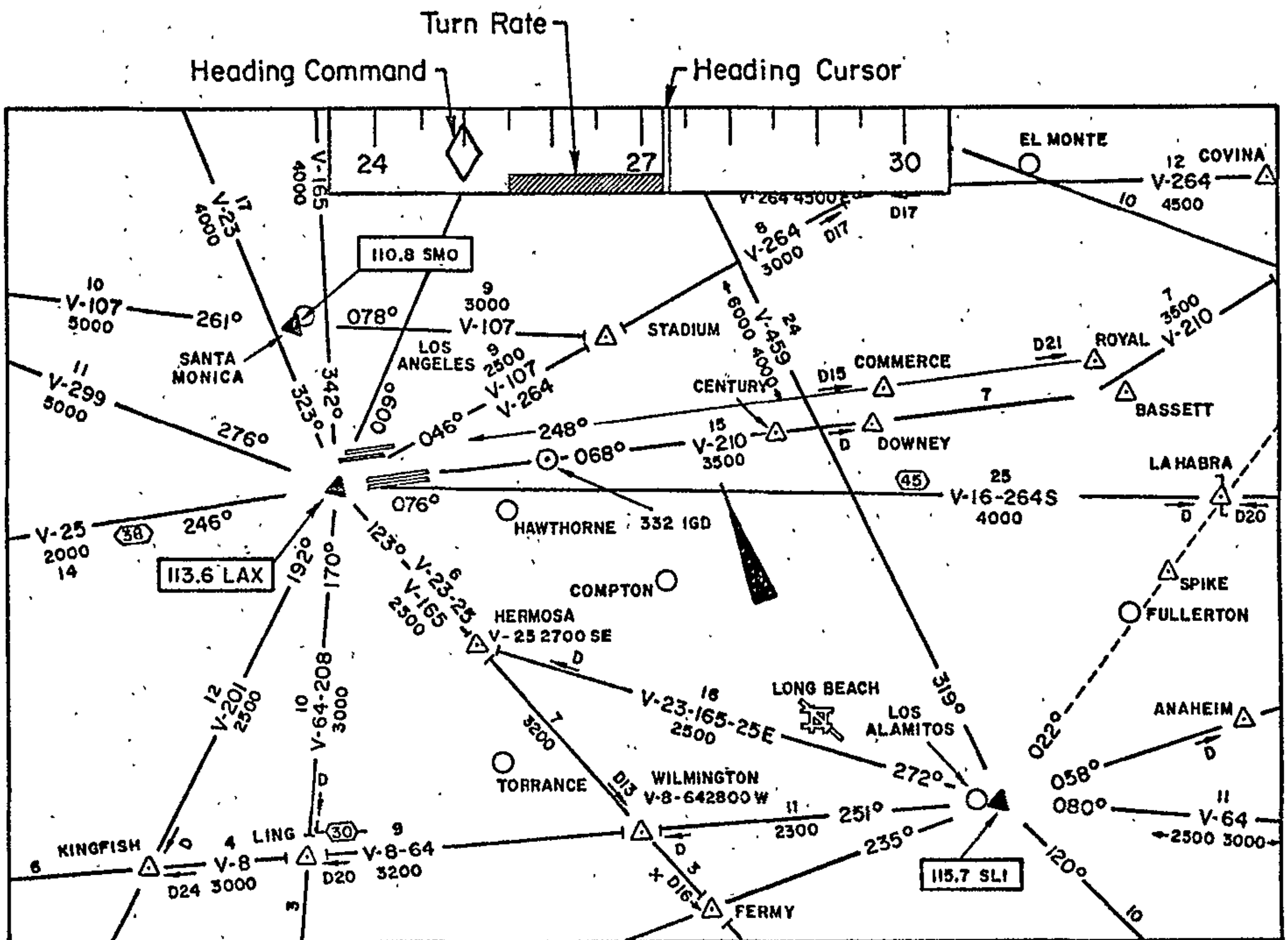
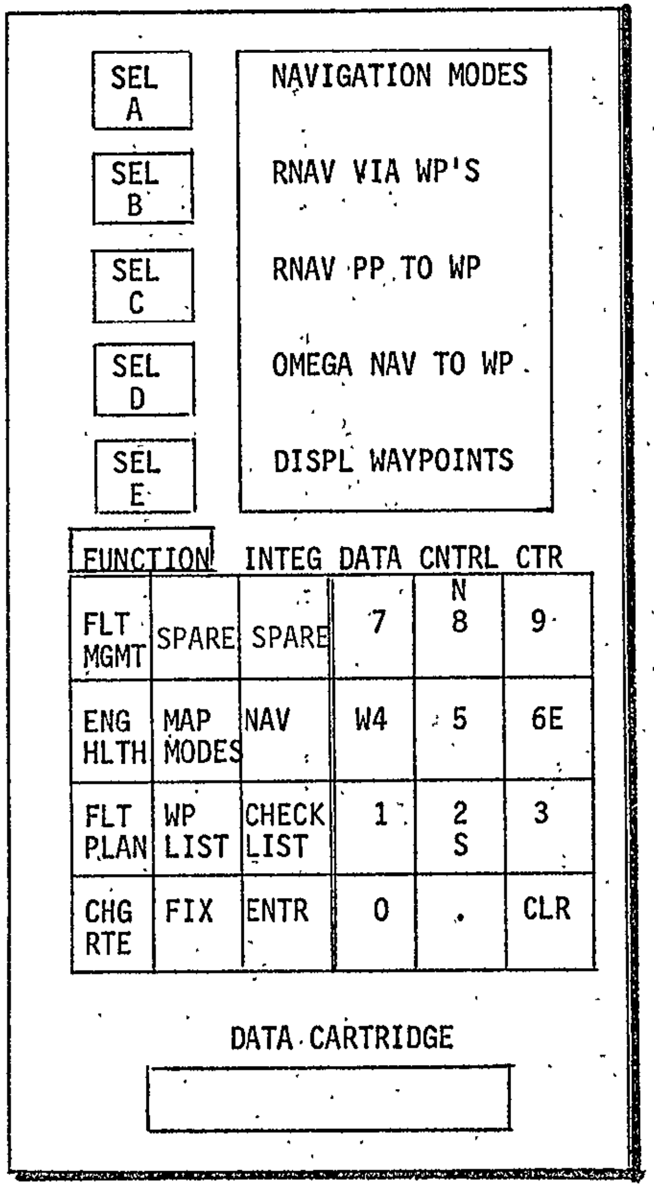


Figure 2. En Route Mode of Navigation Map Display



- COMPLETE AVIONICS SYSTEM MANAGEMENT
- ALL FUNCTION/MODE SELECT EXCEPT AFCS
- COMM/NAV/TRANSPONDER FREQ MGMT
- DATA CARTRIDGE FOR MASS MEMORY
  - CONUS NAV DATA
  - CHECK LISTS
  - POWER MGMT LOOK-UP TABLES
  - OTHER SYSTEM DATA
- 8 BIT MICROCOMPUTER/MASTER CONTROL
- IEEE 488 PARALLEL BUS INTERFACE WITH
  - NAV DATA & TUNING UNIT
  - NAV MICROCOMPUTER
  - FLT SENSOR DATA UNIT
  - NAV MAP DISPLAY

Figure 3. Preliminary Control/Display Format

The IDCC consists of a fixed keyboard for numerical data entry and for selecting functions. Variable selection keys are located adjacent to the CRT which displays variable selection options which depend upon the mode or function selected by the fixed keys. This arrangement provides an unlimited array of mode selection capability which can be changed by software in the MCC.

The selection and location of other instruments and controls on the PCAAS panel are discussed in the section entitled "PCAAS Instrument Panel."

System Design

The PCAAS system design was supported by tradeoffs that considered a wide variety of PCAAS candidate options. The emphasis in the tradeoffs was for the Intermediate system selections.

System block diagram.-The PCAAS Intermediate system block diagram is presented in Fig. 4. The heart of the system consists of a distributed processor architecture Microcomputer Control Complex (MCC). The PCAAS functional computations are distributed among the seven processors with software (firmware) functional redundancy provided.

The navigation and communication radios are interfaced with Microcomputer No. 1 (frequency management). This processor provides frequency commands to the radios and receives the navigation data in digital form from the radios.

The low-cost OMEGA navigation system interfaces with the MCC via an RS 232C serial I/O. The OMEGA system provides line of position data in digital form which is converted to latitude and longitude position in Microcomputer No. 2 (navigation). The navigation processor provides all necessary navigation and guidance computations.

There is minimal interface between the surveillance elements and the MCC. The transponder codes are commanded from the IDCC and the digitized pressure altitude signal is transmitted to Microcomputer No. 3 (flight

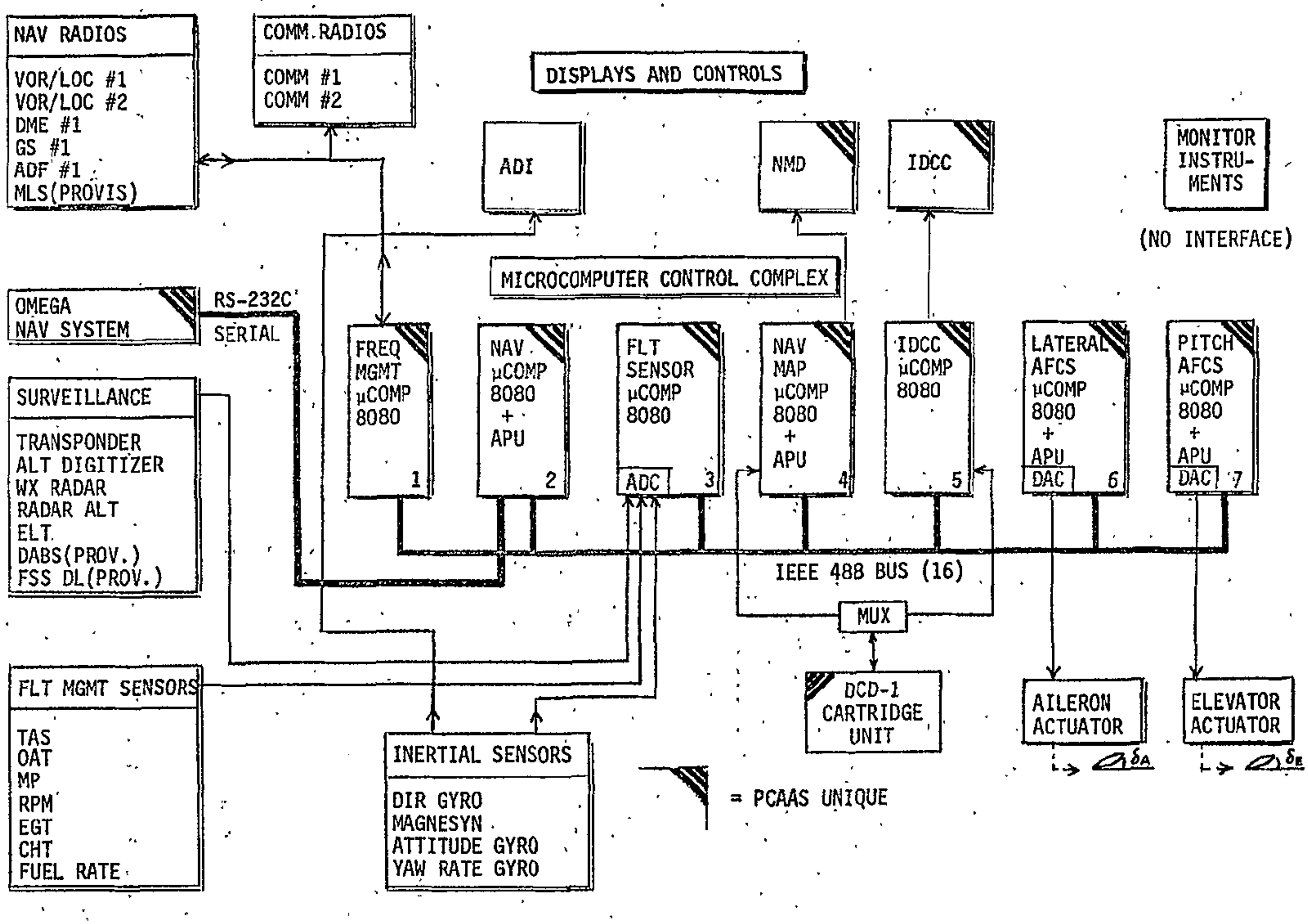


Figure 4. PCAAS Block Diagram

sensors). The radar altimeter signal is provided to Processor No. 3 for use in the ground proximity warning algorithm.

The flight management sensors provide the basic sensor data for a number of the flight management and engine management computation functions. The electrical outputs of these sensors are introduced through appropriate analog to digital converts (ADC) in Processor No. 3.

The inertial sensors which provide attitude and rate signals for the guidance and automatic flight control computations are also introduced through Processor No. 3.

The navigation map processor (No. 4) provides the computations and interface for the Navigation Map Display (NMD). The navigation map receives navigation file data from the cartridge unit mass memory.

The IDCC processor (No. 5) provides the computations and interface for the IDCC keyboard and display. The IDCC processor also has access to the navigation and other file data stored on the cartridge mass memory.

The autopilot computations are divided between a lateral AFCS processor (No. 6) and a pitch AFCS processor (No. 7). Both of the AFCS processors have digital to analog converters (DAC) to drive the surface actuators.

The PCAAS unique items are shown by a shaded corner in the block of Fig. 4.

Data bus.-The PCAAS has two types of data bus. One bus is internal to the microcomputers for transferring data between the CPU and other associated microprocessor chips. The system data transfer bus utilizes the IEEE 488 16-bit parallel data bus. This bus permits any processor to be a "talker" or a "listener." Each processor is assigned an address to permit system data to be transmitted over the bus to the various users of the data.

A time slot concept permits transfer of the bus control from one processor to another. In the event that the IDCC processor (No. 5), which is the principal bus controller, fails, provision is made for transferring bus control to another processor.

Modularity.-The PCAAS architecture is such that new system functions can be easily added (or existing functions can be deleted). For example, if the FAA should implement a VHF digital data link capability, the required Modem to receive and transmit the digital data in Frequency Shift Keying (FSK) format would be added to an existing I/O module of the frequency management microcomputer (No. 1). The data receiver would be placed on the IEEE 488 bus for these users needing the data. In that case the firmware in the IDCC would require a minor modification to permit the mode control for the VHF digital data link.

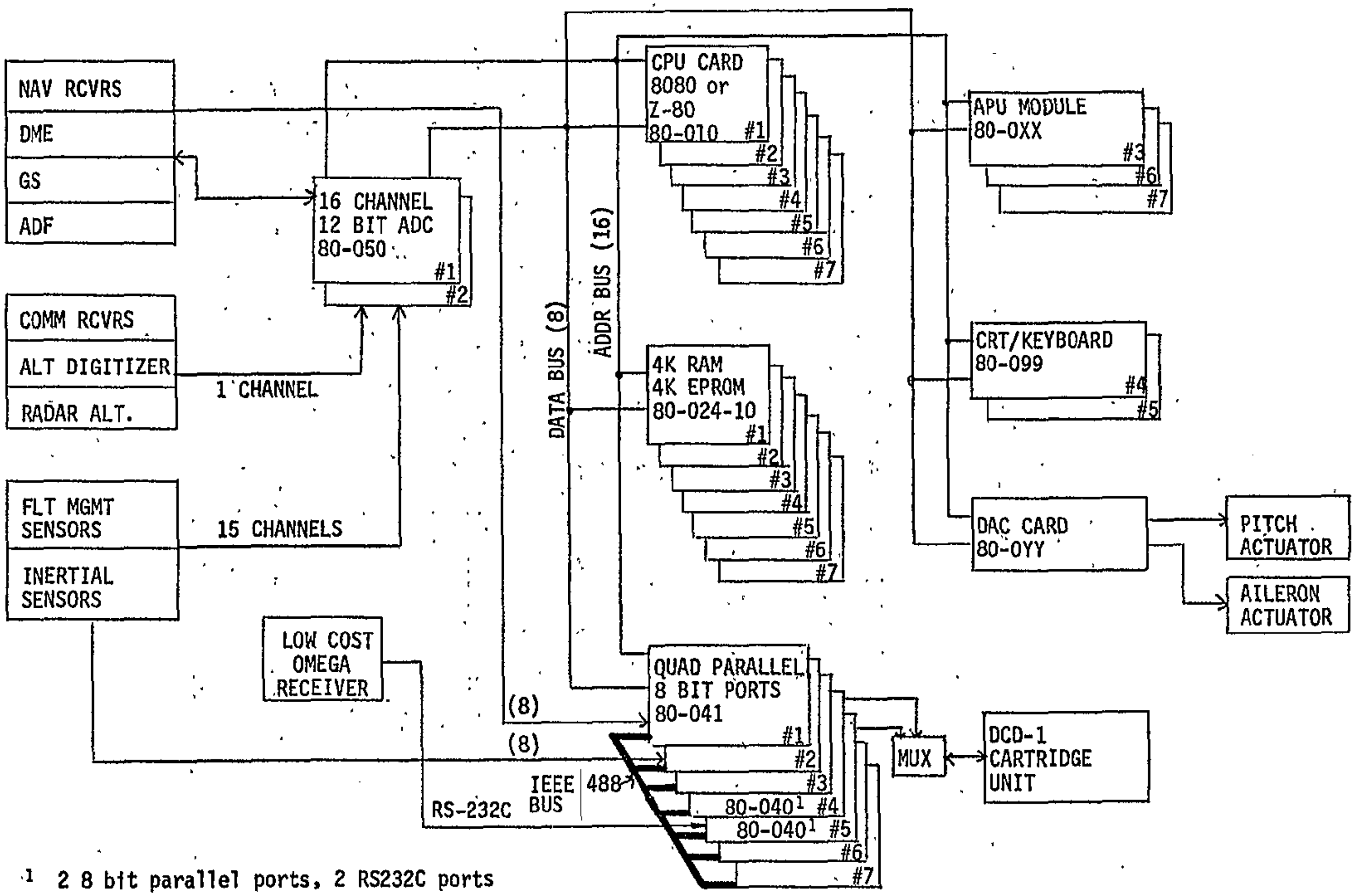
Maintenance philosophy.-The PCAAS maintenance approach takes advantage of the MCC capability to isolate failures using special test routines. The MCC test routines would isolate a failure to a line replaceable unit (LRU) or "black box." The LRU would be taken to the general aviation maintenance shop at the airport. Repair of the black box would be accomplished by replacing failed modules.

Some of the more sophisticated avionic shops would have the capability of repairing modules in the field. However, as a general rule the modules would be returned to the factory for repair.

Microcomputer Control Complex

The MCC configuration is illustrated in Fig. 5. The MCC is implemented using standard off-the-shelf modules. These modules include the central processor unit (CPU) cards, random access memory (RAM), and erasable programmable read only memory (EPROM) cards, parallel 8-bit I/O cards, CRT/keyboard I/O cards, arithmetic processor unit cards, and 16-channel, 12-bit ADC cards. The use of these off-the-shelf cards which utilize the 8080 or Z-80 Microprocessor greatly reduces electronic non-recurring design costs. Standard card cages and cabling are available to further simplify the design task.

The approach to the MCC software is illustrated in Fig. 6. A higher order language (HOL) will be used for programming the required PCAAS algorithms. The HOL program will be augmented with assembly language subroutines when necessary for such areas as I/O subroutines. A compiler



[1] 2 8 bit parallel ports, 2 RS232C ports

Figure 5. PCAAS Microcomputer Control Complex (MCC)

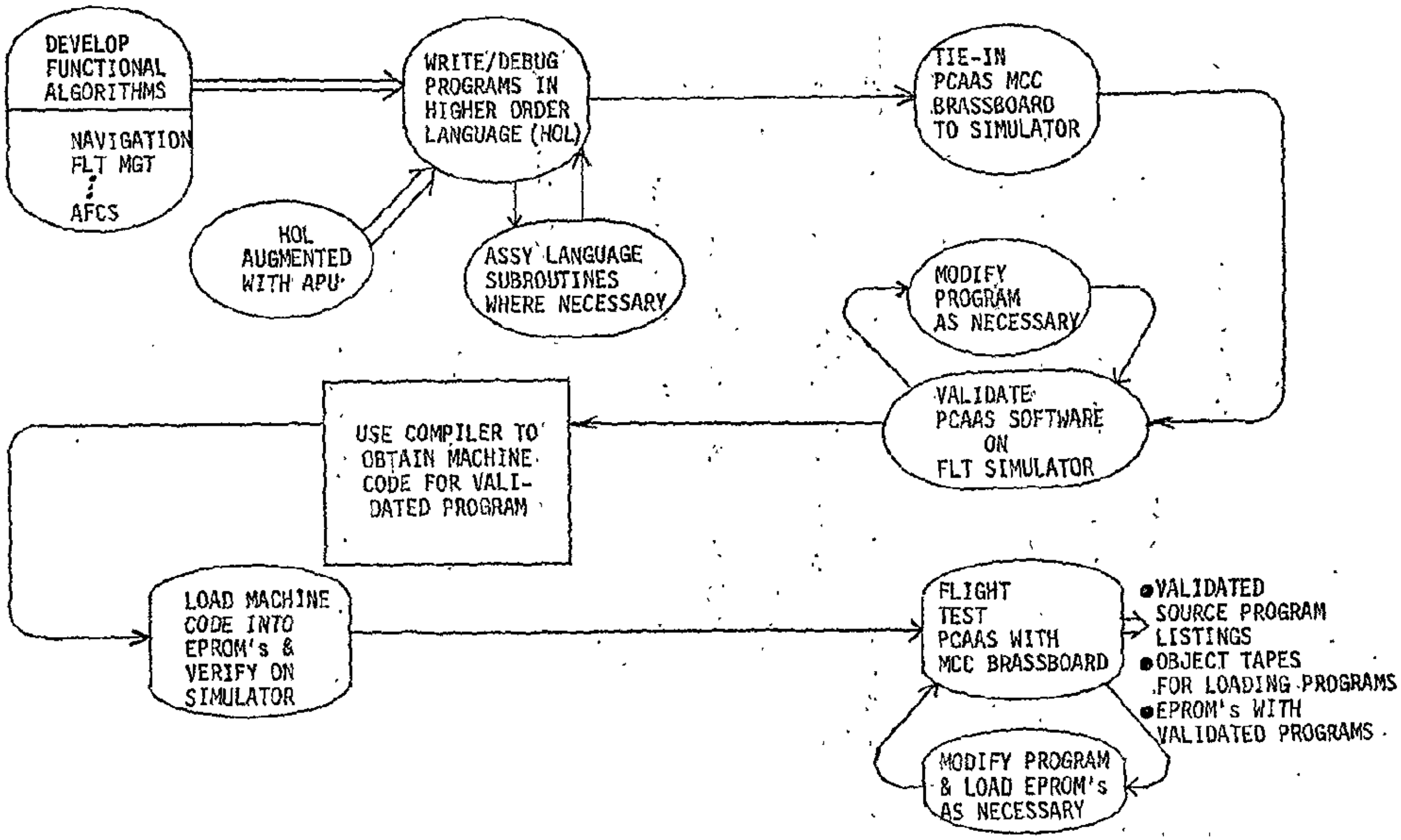


Figure 6. Approach to PCAAS Software

will be used to convert the HOL program into machine code which can be loaded into the 8080 or Z-80 processor memory. The PCAAS software will be validated on a flight simulator and then loaded into EPROM's for the flight software (firmware).

Conclusions and Recommendations

- The PCAAS achieves increased avionics capability by:
  - Overall system integration through the MCC.
  - Central avionics system management by the IDCC.
  - Pilot orientation from Navigation Map Display.
- A new, low-cost OMEGA is required to achieve cost goals.
- Existing NAV/COM radios need provision for frequency command.
- The PCAAS utilizes considerable off-the-shelf avionics in fulfilling the objectives.
- Advanced ATC functions are provided through modularity growth.
- Key interim developments which NASA should support:
  - Low-cost OMEGA.
  - Use of arithmetic processor unit for AFCS and navigation computations.
  - IDCC detailed specification and design.
  - NMD detailed specification and design.
  - No-gyro state vector sensor/processor.

INTRODUCTION

Objectives of Preliminary Candidate Advanced Avionic System (PCAAS)

The PCAAS system has two primary objectives. They are:

- To assist a single pilot in conducting a safe (IFR) or high density (VFR) flight in a complex general aviation aircraft.
- To utilize advanced technology to enhance general aviation avionics capability and reliability at affordable costs.

System Design Philosophy

The underlying motivation for the design of an Advanced Avionic System is to enhance safety by reducing the pilot workload. Improvements in displays and controls on currently existing systems would reduce workload but not by the order of magnitude required to operate a complex aircraft in high density terminal areas with one pilot. A system design philosophy was adopted to achieve workload relief through the use of modern digital technology to perform part or all of the functions normally accomplished by a second pilot. This resulted in two basic display and control system elements: the Integrated Data Control Center (IDCC) and the Navigation Map Display (NMD). A Microcomputer Control Complex (MCC) is provided to accomplish the required computations. These elements are described in subsequent sections.

Design Guidelines

The development of the Preliminary Candidate Advanced Avionic System was carried out under the following design guidelines

- Allow single pilot IFR in high density terminal control areas.
- The system costs shall be no greater than the installed cost of current light twin avionics.

- The system shall be designed for both single engine and light twin engined airplanes.
- The required proficiency shall be no greater than the current IFR pilots.
- The reliability of the PCAAS system shall be equal to or greater than current avionics.
- The system shall be modular to allow the user to update the avionics.
- The system shall be compatible with the UG3RD air traffic control system currently being planned by the FAA.

PILOT WORKLOAD CONSIDERATIONS

Tasks which are considered to be major workload contributors are listed in Table 3. Also listed in Table 3 are current methods of workload relief. The aircraft industry has paid a great deal of attention to Items 1 and 2, control of aircraft attitude and keeping the aircraft on course and altitude. As a result of this research, general aviation manufacturers offer a wide range of autopilots and flight directors. It will be noted, however, that the only current method to relieve the pilot of the workload represented by Items 3 through 8 is to have a second pilot. In cases where this is not possible these items are accomplished using rules of thumb under the assumption that an approximate solution is better than no solution or, in some cases, accomplished at the expense of some other in-flight task.

Based on the above considerations, it seems obvious that major pilot workload relief could be obtained if the copilot functions can be defined and mechanized using advanced digital microprocessor technology. To satisfy this need, we have developed the Integrated Data Control Center (IDCC) and the Navigation Map Display (NMD) supported by the MCC described in the following sections of this report.

It must be recognized that if the IDCC, NMD, and MCC are to achieve the primary objective of the PCAAS program in reducing pilot workload, reliability must be very high. This stems from the fact that more excess workload capacity can be used up in verifying that a system is working than the achievable workload reduction of the system in the first place.

Finally in addition to the design of the IDCC and NMD, the PCAAS system also takes into account the current state-of-the-art of instrument displays and location on the panel. New and revolutionary displays were not selected because of their high risk nature. It is felt that separate research programs should be undertaken to evaluate such (new) displays before being incorporated into an Advanced Avionic System.

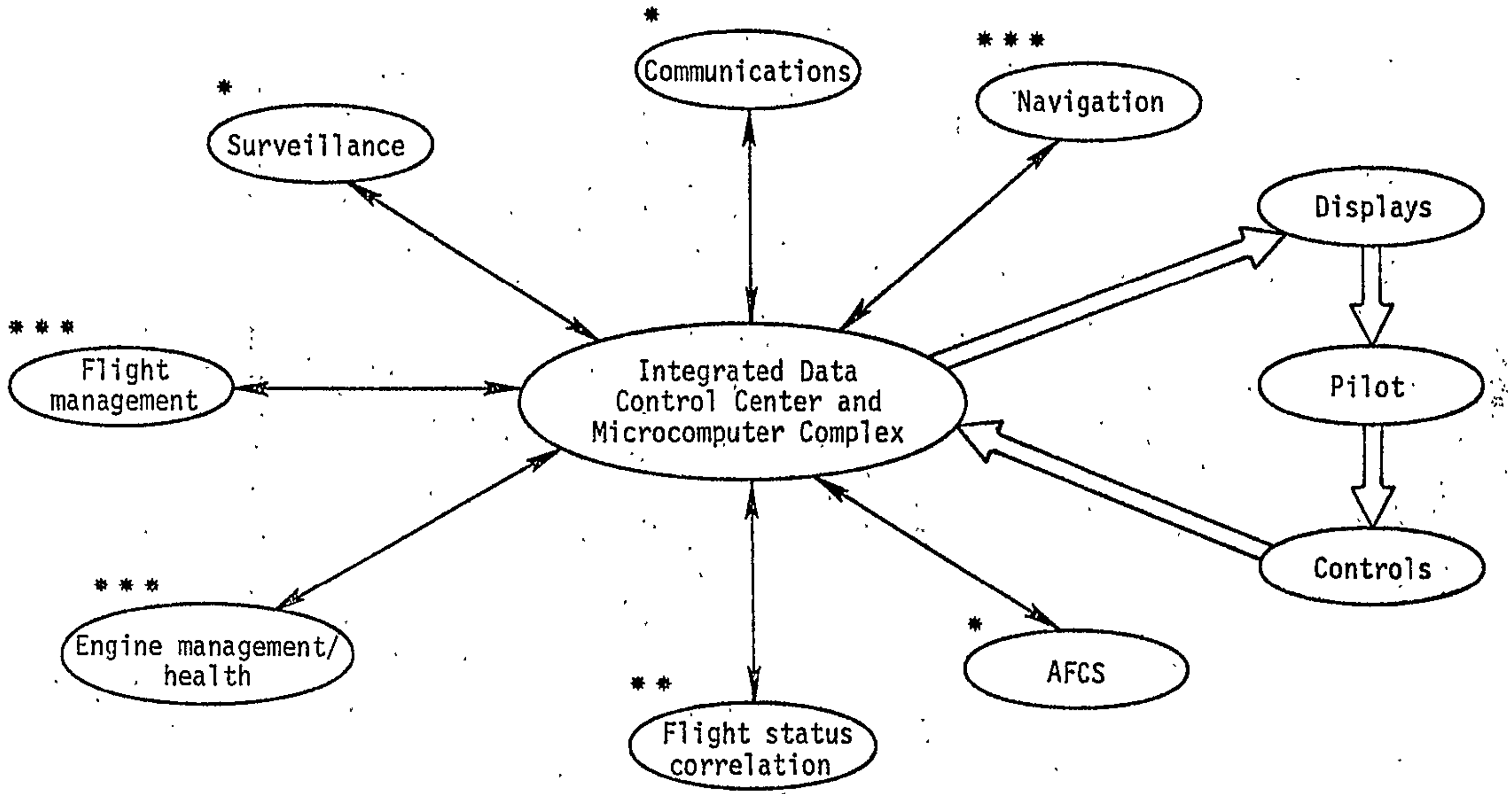
TABLE 3

PILOT WORKLOAD SURVEY METHOD USED BY PCAAS

Major Workload Contributors	Current Methods of Workload Relief
1. Control of pitch attitude (θ), heading (ψ), and roll angle (φ)	Autopilot with heading hold or copilot takeover.
2. Keeping aircraft on course and altitude	Couplers or copilot monitoring.
3. Maintaining orientation with respect to major navaids and airports	Copilot is only current solution in general aviation.
4. Using proper rpm, manifold pressure, mixture, and wastegate for current flight condition.	Approximate (e.g., inefficient) rules of thumb or have copilot look up required data.
5. Route calculations	Approximate (e.g., inefficient) rules of thumb or have copilot look up required data.
6. Nonroutine calculations: • Nearest alternate at any time • Possible alternates if destination closes	Approximate (e.g., inefficient) rules of thumb or have copilot look up required data.
7. Laying out a new routing assigned by ATC	Approximate (e.g., inefficient) rules of thumb or have copilot look up required data.
8. Monitoring health of airplane systems — in particular autopilot, engine, and avionics	Approximate (e.g., inefficient) rules of thumb or have copilot look up required data.

FUNCTIONAL DESCRIPTION

This section contains a summary of the functions which comprise the PCAAS system. A more detailed description of each of the functions is given later in the section entitled "IDCC Mode Descriptions." The PCAAS functions are shown schematically in Fig. 7. This figure indicates that each function interfaces directly with the Integrated Data Control Center (IDCC). Data is transferred from the IDCC to the pilot (via the displays) who in turn can request information via the controls. The single line arrows in Fig. 7 indicate system mechanization whereas the broad arrows indicate interfaces with the pilot via the displays and controls. The stars shown above each function represent the estimated relative contribution of that function to the overall workload reduction achieved by the PCAAS system. Items with only one star (surveillance communication and AFCS) indicate that these items are relatively independent of the PCAAS system. For example, the automatic flight control system already represents a major reduction in pilot workload. The additional reduction in pilot workload resulting from the PCAAS digital AFCS mechanization is not expected to be significant. The workload reduction of the PCAAS mechanization communications and surveillance functions are also expected to have minor reduction in workload. On the other hand, the flight management and engine management/health functions either do not exist or are primitive in current aircraft avionics. It is therefore expected that the addition of the PCAAS system will allow major reductions in pilot workload via these functions. It is also expected that the PCAAS system will result in major workload reductions via the navigation function (Navigation Map Display). Integration of these functions with the IDCC will allow the pilot to request and obtain such critical items as a continuous update of fuel reserves at the planned destinations or at selected alternates. The flight status correlation function will provide workload relief by performing cross-checks between various aircraft systems. An example of flight status correlation would be the checking of one VOR receiver against the other on a continuous basis. The Integrated Data Control Center (IDCC) will display information to the pilot via a dedicated CRT surface. The pilot-system interface will



Note: Stars above functions indicate their relative contribution to workload reduction.

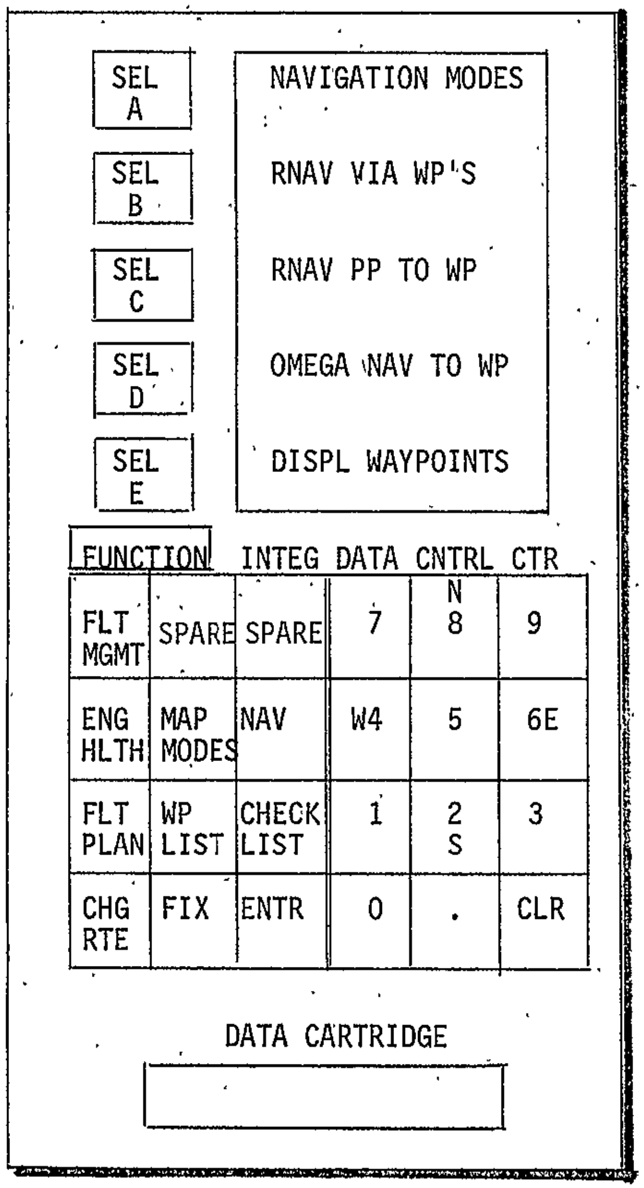
Figure 7. PCAAS Function Summary

be accomplished using question and answer prompting, thereby minimizing the need for the pilot to learn special purpose code names and instructions.

Pilot control of the system will utilize both the distributed and centralized function selection techniques. Distributed functions imply that the pilot input is made at some dedicated position on the panel where the function is displayed. Distributed functions will be utilized for radio frequency inputs as well as selection of autopilot and automatic flight control system modes. Centralized function selection will be utilized for all other functions. As discussed in Ref. 1, all distributed functions will be post designated, whereas the centralized functions will be predesignated. For example, in order to select a radio frequency the pilot will first key-in proper number at a centralized point on the panel (IDCC panel) and secondly will designate which radio that function is to be assigned to (post designation).

It is felt that items which have a direct effect on the control of the aircraft should have a distinct location on the instrument panel and should be changeable at any time without disturbing secondary calculations which are being performed. For this reason, the automatic flight control system and autopilot mode controls are not only functionally distributed but also physically located away from the IDCC panel. It might be argued that this is consistent with the pilot-copilot interaction wherein one crew member will assume responsibility for control of the aircraft while the other performs the other functions such as engine management, flight management, and navigation.

The control-display format of the IDCC has not yet been finalized. Because the success or failure of the PCAAS system is so heavily dependent on the pilot/system interface, it is felt that a simulation program is necessary before the final format can be selected. A preliminary format is shown in Fig. 8. In this example the pilot has selected the navigation function. The system has responded by informing him of each of the options available in this function. Upon selecting one of the options shown, the system would then lead him through the selection of waypoints via prompting messages. The decision tree type logic utilized to develop the prompting



- COMPLETE AVIONICS SYSTEM MANAGEMENT
- ALL FUNCTION/MODE SELECT EXCEPT AFCS
- COMM/NAV/TRANSPONDER FREQ MGMT
- DATA CARTRIDGE FOR MASS MEMORY
  - CONUS NAV DATA
  - CHECK LISTS
  - POWER MGMT LOOK-UP TABLES
  - OTHER SYSTEM DATA
- 8 BIT MICROCOMPUTER/MASTER CONTROL
- IEEE 488 PARALLEL BUS INTERFACE WITH
  - NAV DATA & TUNING UNIT
  - NAV MICROCOMPUTER
  - FLT SENSOR DATA UNIT
  - NAV MAP DISPLAY

Figure 8. Preliminary Control/Display Format

messages also represents a key interface item and should be refined during a piloted simulation period. It should be noted that this simulation need not involve moving base or exotic visual displays. The objectives of the control/display interface of the IDCC should include: an easy to read CRT surface area; allowance for the effects of turbulence in utilizing the pushbutton controls; provision for inputting flight plans from an external source (such as a pocket calculator) and finally the ability of the system to display urgent messages without losing the current program. The IDCC format in Fig. 8 is probably inadequate because the CRT surface is too small and because the function select switches are located below the CRT and therefore on the instrument panel. This is a very poor location for function select switches in that the pilot's arm must be extended in a cantilever fashion making it very difficult to push the desired button in turbulence. It is therefore expected that the function select panel will be located on the right or left pilot's arm rest thereby allowing the pilot to use his forearm as a reference point. The data cartridge slot shown in the example control display format in Fig. 8 illustrates that updated navigational data will be entered into the system via tape cartridges. It is expected that these cartridges will be supplied as revisions much in the same way that Jeppeson or the U.S. Government Chart Service supplies revisions to airway manuals at the present time.

Navigation Map Display

Maintaining orientation with respect to major navaids, mountains, and airports in IFR or VFR low visibility conditions currently consumes a major part of the pilot's workload. The reason is that with current displays it is necessary for the pilot to convert needles and numbers into a location on a map which is usually located on the pilot's lap. The introduction of a Navigation Map Display on the instrument panel would greatly reduce the pilot's workload by keeping him oriented at all times. With very few exceptions Navigation Map Displays have involved high cost and heavy projection systems. However, with the advent of microprocessors it is felt that a Navigation Map Display can be developed at a reasonable cost and without the weight penalty incurred by projection systems and the associated synchro-servo hardware. It is proposed that all the required map data can be stored in the microprocessors and displayed on a CRT surface. Considerable research on moving map displays (see Ref. 2) has shown that pilots prefer heading-up over north-up displays, and that the map should move and the airplane should be stationary on the display. The reason that heading-up displays are preferred over north-up displays is that north-up displays tend to induce control reversals when the aircraft is proceeding in a southerly direction. In order to preserve the proper right-left orientation, without incurring the cost of a heading-up display, it is proposed that an octant-up display be utilized. That is, the display shall be oriented so that "up" is within 45 deg of the aircraft heading. Inasmuch as this display represents the ultimate in horizontal situation indication, a conventional HSI is not proposed on the PCAAS panel. In order to provide the scale and declutter required for compensatory tracking, an HSI mode is added to the Navigation Map Display. Hence, the Navigation Map Display can be operated in the en route mode for orientation and in the HSI mode for tracking. An example of each of these modes is shown in Figs. 9 and 10. It will be noted that the vertical situation is also shown in the HSI mode. A horizontal card type heading scale is electronically generated on the navigation map CRT surface. The electronic bug and open diamond is shown on this display to indicate the heading selected either manually or by the autopilot. A conventional compass card will also be included on the panel to allow the pilot to select headings more than 30 deg from the current heading.

The HSI mode (see Fig. 10) utilizes the full CRT display surface. All information except for major navaids is eliminated from the display. It is expected that the pilot will spend most of his time in the HSI mode in order to monitor his deviations from the selected course. The en route mode will be commanded momentarily to indicate overall orientation with respect to navaids, key obstructions, and airports. It is felt that enough information must be included on the Navigation Map Display so that the pilot does not feel compelled to refer to other maps during the flight. Therefore, as a minimum we have proposed that the maps show airports, key obstructions, and navigational aids.

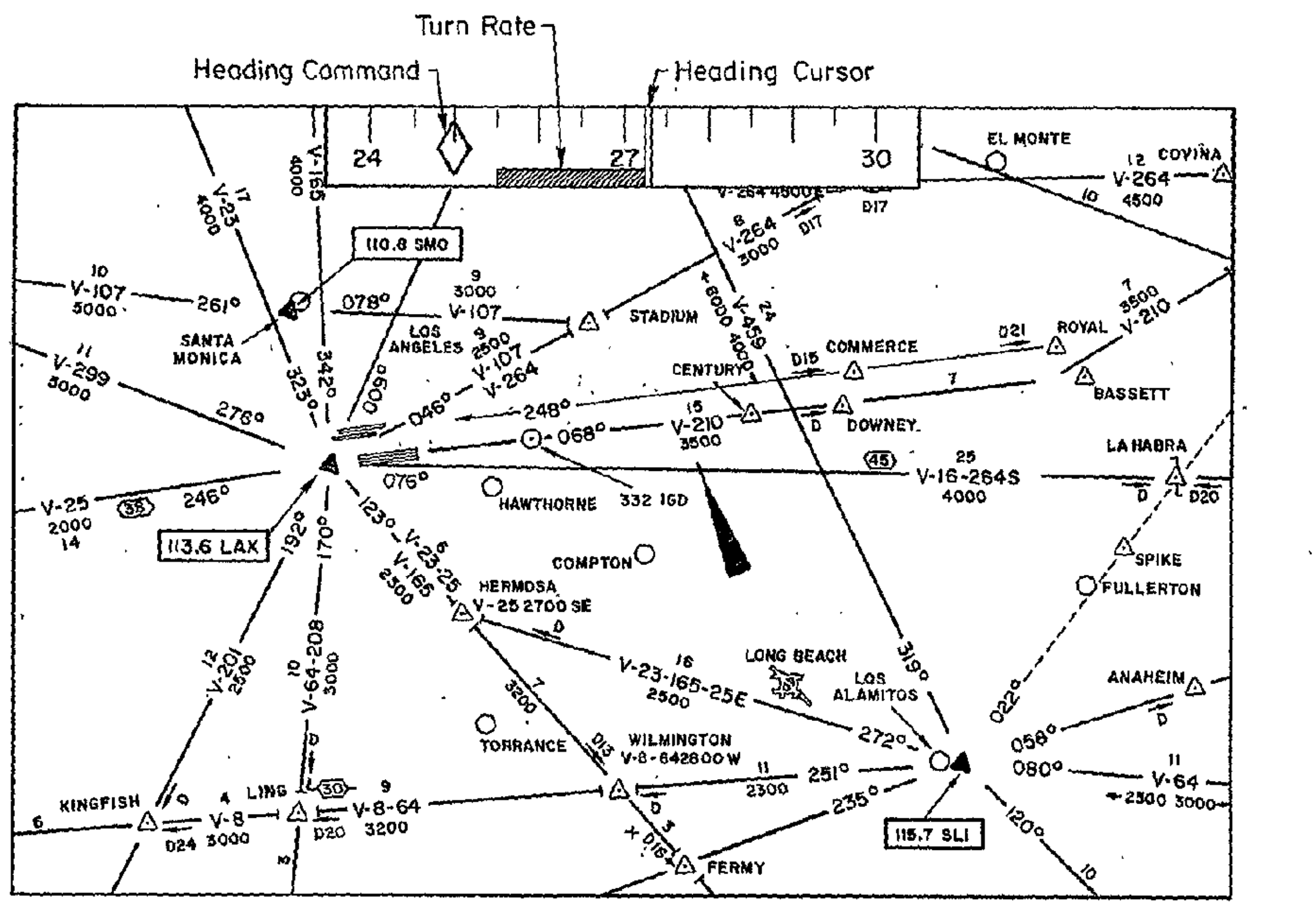


Figure 9. En Route Mode of Navigation Map Display

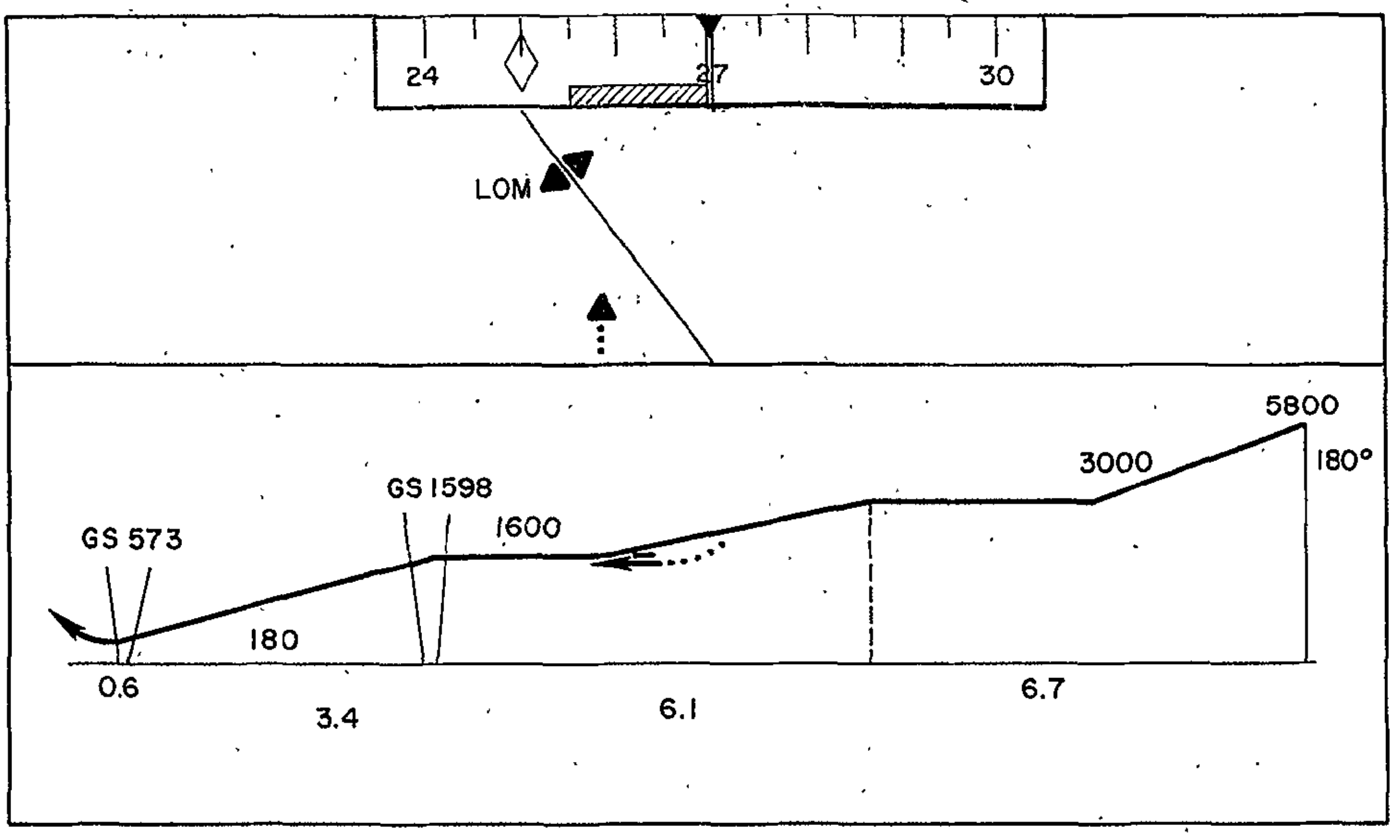


Figure 10. HSI Mode Of Navigation Map Display

The en route map display has selectable scales to provide more sensitivity or a larger overview as desired. Also the NMD can provide a "split screen" display with the HSI and VSD displays shown simultaneously, each on one half of the NMD display surface.

One of the more difficult piloting tasks involving orientation is the circumnavigation of storm areas in low visibility or IFR conditions. One possible solution would be to superimpose radar information on the Navigation Map Display. However, because of cost considerations and because of the possibility of overcluttering the Navigation Map Display, we have proposed a system by which the pilot can set a cursor on the radar display which when selected will transfer that point onto the Navigation Map Display.

Automatic Flight Control System Functions

As discussed earlier, the PCAAS system is organized so that the automatic flight control system is essentially independent of the Integrated Data Control Center and Navigation Map Display. That is, the mode select and display is located at a separate section on the instrument panel from the IDCC or the NMD. However, autopilot modes and aircraft attitudes are available to the IDCC for computation of other functions. In addition, navigation and automatic flight control system functions are integrated through the IDCC so that the pilot may allow the system to fly the selected courses automatically. A summary of automated flight control system functions which are available on current general aviation autopilots is given below. It is not felt that additional functions would appreciably reduce pilot workload. Inasmuch as the primary objective of PCAAS is to reduce pilot workload, no new automatic flight control system functions are recommended.

- Stability augmentation (where required):
  - Damping of spiral mode
  - Damping of dutch roll mode
  - Damping of roll subsidence mode

- Longitudinal control:
  - Attitude hold
  - Altitude hold
  - Airspeed hold
  - Vertical navigation coupling
  - Glide slope coupling

- Lateral control:
  - Standard rate turn command
  - Heading hold and command
  - VOR coupling/RNAV coupling
  - Localizer coupling

The integration of weather avoidance into the IDCC was discussed in the previous section. In addition, the ground proximity warning will also be incorporated into the IDCC to provide flight status correlation between glide slope tracking and terrain avoidance.

Communication Function

PCAAS provides dual 720 channel VHF communications with the COMM (communications) receivers remotely tunable from the IDCC. Backup tuning means is also provided. Provision is included in PCAAS for a digital data link over the VHF (very high frequency) channels. At present the FAA (Federal Aviation Administration) has no facilities for transmitting or receiving digital data. Such a capability would greatly enhance the capability for PCAAS to receive revised ATC clearances and display the same to the pilot for acknowledgement. Such digital ATC clearances would provide an easy way to revise ATC clearances en route without the necessity for the pilot to key in a revised route structure.

Surveillance Function

The PCAAS surveillance function includes the ATC surveillance elements as well as means to avoid extreme weather and to provide ground proximity warning. The surveillance function includes issuing transponder code commands to the ATC beacon received from the IDCC. The surveillance function also includes the altitude reporting function associated with the transponder and provided by an altitude digitizer. The digital altitude is furnished to other functional users of altitude such as navigation and engine management.

Ground Proximity Warning (GPW) is provided by means of a radar altimeter sensor which provides terrain clearance information used in the GPW computation.

The surveillance function includes a weather radar. Provision is made for tying in the range and azimuth cursor information from the weather avoidance radar to the navigation function for lateral guidance around areas of heavy precipitation return shown on the radar screen.

This tie-in is included in the upgrade system with provisions only for the intermediate system. The desired flight path is selected by manually setting a range and azimuth cursor and then designating the intersection of the two cursors as a weather avoidance waypoint. Such flight path deviation requires ATC approval under current IFR procedures.

The surveillance function includes provision for the Discrete Address Beacon System (DABS) and the VHF digital data link should the FAA choose to implement these elements.

The surveillance function includes the mandatory Emergency Locator Transmitter (ELT) which has no interface with other PCAAS elements.

PCAAS INSTRUMENT PANEL

The instrument panel layout for the PCAAS system was primarily oriented toward the intermediate level and more specifically for the Cessna 402 as being representative.

The instrument panel currently envisioned for the PCAAS system is shown in Fig. 11. The rationale used in the selection and location of the display shown in Fig. 11 is given in the following two subsections.

Displays

The key elements of the PCAAS system consist of a Navigation Map Display and the Integrated Data Control Center and are located in prominent locations on the instrument panel. As discussed earlier, the version of the IDCC shown in Fig. 11 requires further refinement and is not considered to be complete at this time.

A careful review of the literature was made to determine the current state-of-the-art for each of the other flight instruments. The results of the tradeoff analyses for and against the Electronic Attitude Director Indicator (EADI) and the mechanical Attitude Director Indicator (ADI) are given in Table 4. As can be seem from Table 4, a mechanical ADI is the logical choice at this time. The decision to use a mechanical ADI was heavily influenced by the argument that a large colored display could be developed at reasonably low cost. This is not the current situation in general aviation. Current low-cost attitude gyros are all of the standard three and one-eighth inch variety which we consider to be too small. Unfortunately the large five inch display instruments are built only for upgrade systems and are therefore extremely expensive. The cost drivers on the large attitude gyros do not stem from size but rather from the fact that most of them are driven remotely and involve expensive synchros, erection cutout systems, and other exotic features normally not associated with low-cost general aviation instruments. For the development of the prototype PCAAS system it is recommended that a large attitude indicator be purchased without the remote gyros and synchros, and a standard general aviation

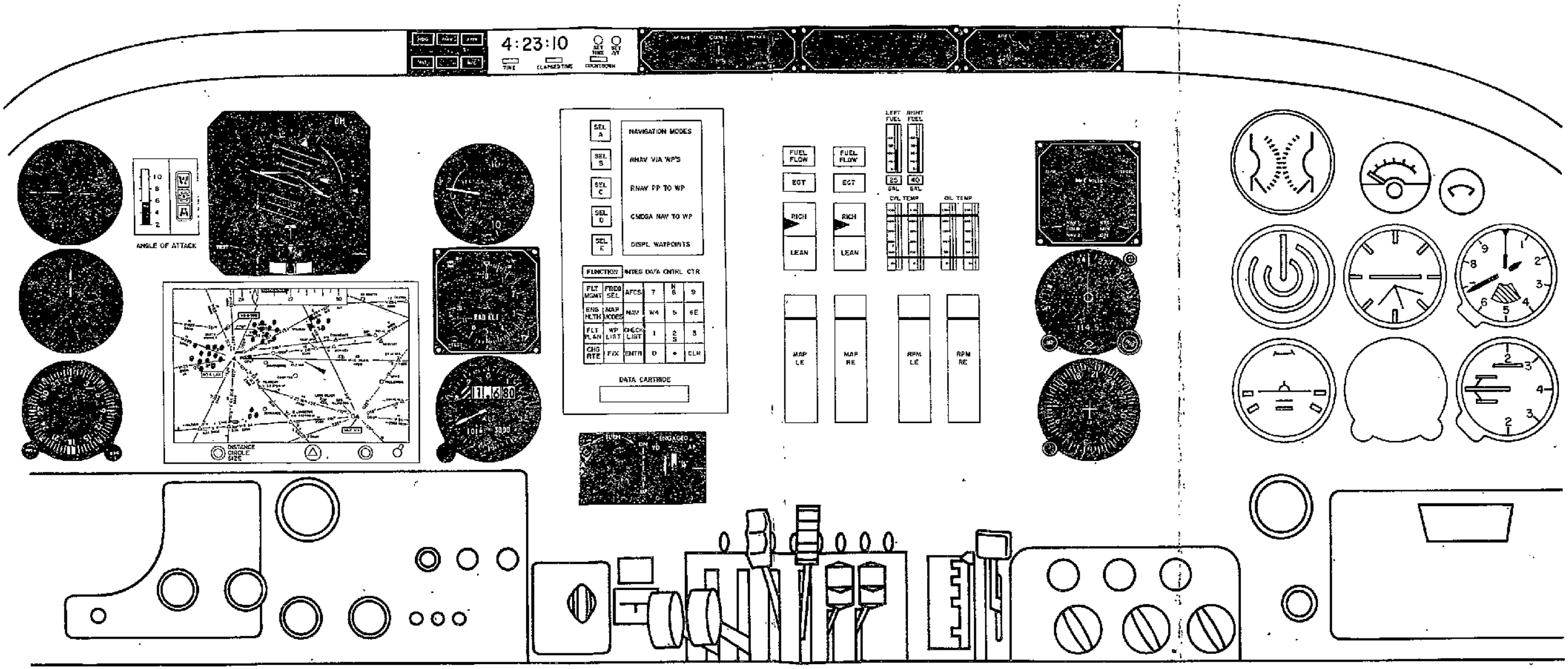

4:23:10
ANGLE OF ATTACK
NAVIGATION MODES
RNAV VIA WP'S
RNAV PP TO WP
OMEGA NAV TO WP
DISPL WAYPOINTS
FUNCTION
INTEG DATA CNTRL CTR
FLT MGMT
FREQ SEL
AFCS
ENG HLTH
MAP MODES
NAV
FLT PLAN
WP LIST
CHECK LIST
CHG RTE
FIX
ENTR
CLR
DATA CARTRIDGE
DISTANCE CIRCLE SIZE
FUEL FLOW
EGT
RICH
LEAN
LEFT FUEL
RIGHT FUEL
CYL TEMP
OIL TEMP
MAP LE
MAP RE
RPM LE
RPM RE

TABLE 4

TRADEOFF CONSIDERATIONS BETWEEN MECHANICAL ADI AND CURRENT "LOW-COST" CRT EADI

MECHANICAL ADI		CURRENT "LOW COST" EADI	
ADVANTAGES	DISADVANTAGES	ADVANTAGES	DISADVANTAGES
Extremely high reliability No risk Color visible in bright sunlight Can be independent of microcomputer Low weight and power	Cannot change functions or scale for different flight regimes Low growth potential	Can display any desired function (only limitation is clutter) Easily rescaled Can split screen or overlay high priority messages High growth potential	Color not visible in sunlight High weight (45 vs. 9.5 lb) High power required (200-225 W) High cost ($20K vs. $10K) Staircase diagonal lines preclude lower-cost raster scan tubes Environment (pressure cycling and vibration) may be unique application of CRT

vertical gyro be installed to mechanically drive the ADI. It is felt that the risks involved in such a modification is relatively low when compared to the tremendous improvement over current general aviation attitude indicators.

The digital plus pointer type altimeter shown in Fig. 11 was selected on the fact that it appears to be superior to vertical tapes or counter drum pointer instruments. The three-pointer type altimeter which is currently most popular in general aviation aircraft should be avoided in that both research and practical experience indicate that it is prone to both 100 and 1000 ft reading errors. The altimeter shown in Fig. 11 is priced well above the cost goals established for the PCAAS system. However, the availability of digital altitude information from the IDCC will make it a simple matter to modify the existing three pointer altimeter to the display shown in Fig. 11. This is one of many examples which illustrate how the concept of an integrated system can bring the cost of exotic displays within the realm of possibility for general aviation. The required reliability will be provided by transmitting the output of the pressure transducer directly to the instrument (without passing through the IDCC) to avoid the possibility of losing altitude information in the event of an IDCC failure.

A conventional vertical speed indicator has been implemented in the PCAAS system. References 3 and 4 indicated that vertical tapes and circular dials are about equal in terms of errors susceptibility. The circular dial was picked on the basis of minimizing changes that did not appear to have a significant impact on pilot workload.

A round dial format was used for the radar altimeter since it has none of the deficiencies (interpretation of trend and rate) of a vertical tape display and none of the 1000 or 10,000 ft discrepancies associated with round dial altimeters.

Dial format was also used for the airspeed indicator. The vertical tape and thermometer type displays were eliminated on the basis of previous experience (U.S. Air Force) which indicated that the increments were too small on these types of displays. It is expected that angle of attack will be the primary flight reference during approaches and climb outs. The angle of attack display shown in Fig. 11 was borrowed directly from the North American B-1. This display is attractive in that it shows angle of attack trends via the thermometer display as well as discrete chevrons which have been found to be extremely successful by Navy pilots.

Thermometer type displays have been used to allow a presentation in which all the engine indications appear at a straight line across the panel. While this is an attractive display format, it is not felt that the contribution to the pilot workload reduction will be significant. It may therefore be desirable to utilize the existing engine instruments in order to keep the PCAAS design cost within bounds.

The mixture command indicators are an integral part of the engine management system. These indicators shall be compensated in the same fashion as a flight director to allow the pilot to lean rapidly, thereby decreasing workload.

Organization of the PCAAS Instrument Panel

The PCAAS panel is organized so that quantities used for inner-loop control are displayed in a central location. Thus, the Attitude Director-Indicator (ADI) is located in front of the pilot at eye level. The instantaneous vertical speed indicator is located just to the right of the ADI in that it represents an intermediate control loop. The radar altimeter is located just below the IVSI. It represents the outer loop during the later phases of the approach when rapid efficient scan is critical. The digital/pointer altimeter is located just to the right of the Navigation Map Display and below the radar altimeter. This location was selected because the barometric altitude is primarily used in conjunction with navigation activities of the pilot. Hence, it is located next to the Navigation Map Display. Angle of attack is defined as an inner loop during critical phases of the approach. Therefore, the angle of attack meter is located next to the ADI (on the left). The backup attitude gyro is located to the left of the angle of attack indicator and is in line with the ADI to maximize pilot awareness of discrepancies between the primary and backup attitude instruments. The airspeed indicator is located just below the angle of attack indicator. Airspeed is considered to be an intermediate loop and therefore should be as close as possible to the ADI.

The lateral displays are similarly organized in that the needle and ball (inner loop quantities) are located directly at the bottom of the ADI. The heading indicator which represents an intermediate loop is located just below the needle and ball at the top of the navigation map CRT display. Heading command and turn rate are also shown on the heading indicator. The Navigation Map Display represents the outer guidance loop and is therefore located below the heavy indicator. As discussed earlier, this display can be utilized in the map mode as shown in Fig. 9 or in the HSI mode as shown in Fig. 10.

The controls and displays for the Integrated Data Control Center are located on a large panel area just above the throttles. This is done so the pilot's right hand can select IDCC commands with a minimum of motion. Additionally, no leaning or head motion is required to read IDCC messages or make selections on the IDCC panel. As discussed previously, the IDCC keyboard will probably be located off the instrument panel and possibly on the right or left hand arm rest to account for the effects of turbulence. The autopilot select panel is located just below the IDCC. It is separate from the IDCC to allow the pilot to select different flight modes without interrupting the information flow between the pilot and IDCC. The location of the IDCC panel or the pilot's mode select panel should be located such that the pilot's right hand should be convenient to both the throttle and the mode select panel.

PCAAS SYSTEM MECHANIZATION

System Configuration

The overall system configuration for the Intermediate system is shown in Fig. 12. The Basic system is obtained by deleting system elements. The Upgrade system is obtained by adding system elements and upgrading other elements. The heart of the system is the seven processor Microcomputer Control Complex (MCC). Data is transferred among the seven processors by means of an IEEE 488 parallel bus.

The MCC receives inputs from the navigation radios, the OMEGA navigation subsystem, the surveillance elements, the flight management sensors, and the inertial sensors. The displays and controls include the Attitude Director Indicator (ADI), Navigation Map Display (NMD), and the Integrated Data Control Center (IDCC). A 100 K byte mass memory (data cartridge) is provided as a part of the MCC.

The two automatic flight control subsystem processors drive the aileron and elevator actuators through digital to analog converters (DAC's).

The PCAAS system elements for the Intermediate system are summarized in Table 5. The PCAAS is configured using off-the-shelf elements except for those items denoted as "new PCAAS" in Table 5. The physical parameters for PCAAS tabulated in the table include the weight, volume, power, failure rate, and estimated user cost. The totals for the "new PCAAS" elements are summarized in the last line of Table 5.

The off-the-shelf elements were selected on the basis of the lowest cost element which met the functional requirements for PCAAS. Although specific models were selected, in each case there are several alternatives to choose from with similar cost and characteristics. Consequently, PCAAS is <u>not</u> committed to any of the selections.

<u>Navigation and communication radios</u>.-Navigation receivers: The navigation and communication radios were considered together during the selection process for the PCAAS. Many of the general aviation avionics manufacturers combine the navigation (VOR/LOC) receiver with the COM transceiver in a

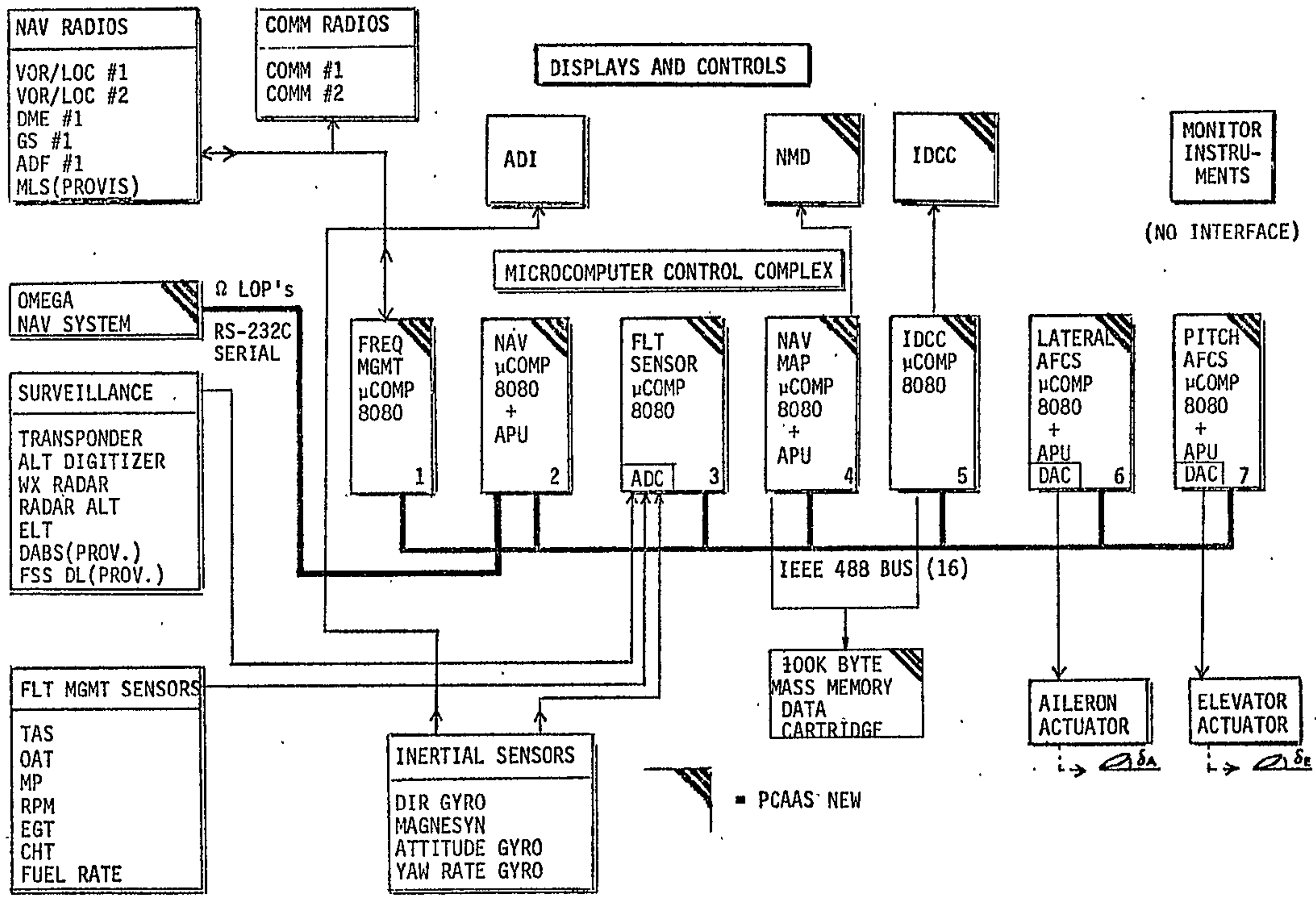


Figure 12. Intermediate System

TABLE 5. PCAAS SYSTEM PARAMETER SUMMARY

PCAAS ELEMENT	MODEL	QTY/ SYSTEM	WEIGHT IN LBs.	VOL. CU. IN.	POWER WATTS	FAIL/ 10^6 HRS[1]	USER COST
NAV RADIO #1	COLLINS VIR-350	1	3.7	101	11.2	1000	$1,400
NAV RADIO #2	NARCO 122[2]	1	3.3	114	12.0	1000	1,700
DME	KING KDM 705A	1	9.3	252	24.0	800	4,200
ADF	NARCO ADF-141	1	6.8	98	5.5	500	1,500
OMEGA NAV	NEW PCAAS	1	17.2	737	24.5	2500	6,000
COMM RADIO	COLLINS VHF-250	2	6.6	203	67.8[3]	2200	2,000
TRANSPONDER	KING KT78A	1	3.0	83	14.0	250	600
WEATHER RADAR	KING KWX-40	1	20.0	262[4]	68.8	4000	5,500
RADAR ALTIMETER	BONZER MINIMARK	1	2.5	105	8.4	500	1,000
ELT	NARCO MRB 510	1	3.0	85	-0-	250	125
ALTITUDE DIGITIZER	AEROSONIC 1019	1	1.8	54	4.2	125	550
IAS SENSOR[5]	BOURNS 503	1	0.6	4	0.1	50	90
PRESS ALTITUDE SENSOR[5]	BOURNS 408	1	0.6	4	0.1	75	80
OAT SENSOR[5]	MICROSYSTEMS -40 to +150°F	1	0.3	4	0.1	75	30
MANIFOLD PRESSURE[5]	BOURNS 409220	2	1.6	8	0.2	150	170

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1. All failure rate data estimated
2. Includes glide slope & marker beacon receivers
3. *During transmit, 23.5W on receive*
4. Plus 12" antenna in radome
5. DC output

(continued on following page)

TABLE 5. (Concluded)

PCAAS ELEMENT	MODEL	QTY/ SYSTEM	WEIGHT POUNDS	VOL. CU. IN.	POWER WATTS	FAIL/ 10^6 HRS[1]	USER COST
FUEL FLOW RATE[2]	WAUGH MF-16-509	2	1.6	12	-0-	100	$ 250
EGT SENSORS	AVICON SAFE SENSORS	8	1.0	8	0.1	200	1,000
HSI & DIR GYRO	NARCO HSI 100S	1	5.4	150	20.0	1000	3,000
ADI		1	5.4	150	10.0	1000	2,600
YAW RATE GYRO	HONEYWELL JRH 20	1	1.8	13	2.0	250	300
MCC	NEW PCAAS	1 LOT	20.8	450	100.0	250	8,775
STATUS DISCRETES	NEW PCAAS	5	1.0	10	0.5	125	300
TAPE CARTRIDGE	3M DCD-1	1	3.0	60	49.5[3]	250	300
IDCC	NEW PCAAS	1	9.1	287	17.5	1000	2,000
NAV MAP DISPL	NEW PCAAS	1	9.0	286	16.0	850	2,000
AFCS ACTUATORS	OTS ELECTRIC	2	18.0	150	50.0	1000	1,500
MISC		1 LOT	20.0	250	10.0	500	1,000
PCAAS TOTAL			176 lb	3940 cu. in. (2.28 cu. ft.)	516 w (37 amps)	20,000 (50HR MTBF)	$49,570
New PCAAS Total			49.7 lb	1830 cu. in.	208 w	4,975	$17,900

1. All failure rate data estimated
2. Freq proportional to flow rate
3. 11.0 watts when idle

single case which has shared power supplies. The navigation receivers provide automatic channeling for DME by selection of the VOR frequency and automatic channeling for the glide slope by selection of the localizer frequency.

Separate units were selected for the navigation receiver and the communication transceiver for the Intermediate system in order to have independent units with separate power supplies. Navigation Radio No. 1 is a Collins VIR-350, which has 200 channels in the frequency range of 108 to 117.95 M Hz for ILS localizer and VOR. The DME is automatically channeled when a VOR channel is selected. The unit includes a standby indicator of VOR/LOC deviation and complies with TSO C36b and C40a.

Navigation Radio No. 2 is a NARCO NAV-122 which has the same features as the Navigation Radio No. 1 plus it also includes a 40 channel glide slope receiver and indicator and a 3 light marker beacon receiver. The NAV-122 complies with TSO C35d, C36a, C40a, and C66a. The glide slope frequency range is 329.15 to 335.00 M Hz.

Communication transceivers: The Intermediate system uses dual 720 channel VHF transceivers which cover 118.0 to 135.975 M Hz. The radios selected are the Collins VHF-250 with 10 watts transmitter output, automatic squelch, and self-test. The units comply with TSO C37b and C38b.

Distance measuring equipment (DME): The King KDM-705A DME, which is all solid state electronics, was selected for the Intermediate system. This unit has 200 channels, a peak power of 1000 watts, and has distance accuracy of ±0.1 N mi, or 0.2 percent of distance. The unit complies with TSO C66. The output is digital and displays distance in the range of 0-399 N mi, ground speed in the range of 0 to 999 kt, and time to station in 0 to 99 min. The ground speed and time to station are only valid when the DME station is a waypoint. Consequently, these outputs are unnecessary to the system. THE PCAAS navigation processor derives true ground speed and time to any waypoint which is generally valid. The lower cost DME's use tubes which are considered to be too unreliable.

Automatic direction finder (ADF): The NARCO ADF-141 was selected for the Intermediate system. This unit tunes over the low frequency and broadcast bands from 200 to 1799 K Hz. The unit is digitally tuned in 1 K Hz steps. This unit uses an RMI for display and complies with TSO C41c.

The ADF is not a critical element in the PCAAS system, but rather provides an additional cross-check for the navigation function. The ADF does provide useful functional redundancy. A reasonably accurate position fix can be obtained from successive "cuts" (lines of position) to a station of known latitude/longitude position using a least squares algorithm. This multiple LOP position fixing mode using ADF is considered an optional backup mode and is not part of the PCAAS navigation software.

OMEGA navigation receiver: The OMEGA navigation receiver is a "new PCAAS" element. There are a number of excellent OMEGA navigation systems currently available off-the-shelf at prices ranging from a low of $20,000 to a high of $59,000. These systems are intended to compete with inertial navigation systems (INS) which are two to three times the cost of the OMEGA system. Consequently, a new low cost OMEGA is mandatory if the PCAAS cost goals are to be met. This low cost OMEGA need have only those elements needed to interface the PCAAS navigation processor. The cost objective for this new low cost OMEGA is $6,000 which appears to be a reasonable goal based on the following factors:

- Ohio University is designing a low-cost OMEGA.*
- NASA Langley is supporting a low-cost OMEGA development with a cost goal of $5,000.
- Teledyne has produced a low-cost Marine OMEGA system with latitude/longitude output expected to sell for $10,000.†
- Low-cost Marine OMEGA systems with digital LOP outputs now available for $2,000.‡

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*Lilley, R. W., and R. J. Salter, A Microcomputer Based Low Cost OMEGA Navigation System, Ohio University, July 1976.

†Stoltz, J. R., Applications of Microcomputers to OMEGA Radio Navigation, Teledyne Systems Company, March 1976.

‡Micro Instrument Co., Model DC 1127, January 1976.

OMEGA is a very low frequency (VLF) radio navigation system operating in the internationally allocated frequency band between 10 and 14 K Hz. It is capable of providing all weather navigational service throughout the world with a complex of eight 10 KW transmitters.

The OMEGA navigation receiver provides PCAAS with a world wide navigation capability particularly over water or at low altitude where reliable VORTAC reception is not available.

Air traffic control surveillance elements.-The ATC surveillance elements are shown in Fig. 12, and their characteristics are summarized in Table 5. The interfaces between the surveillance elements and the PCAAS Microcomputer Control Complex (MCC) include: the digitized altitude derived from the ATC transponder altitude encoding mode, the transponder code select from the IDCC, and the radar altimeter output which is used in the Ground Proximity Warning (GPW) algorithm in the Intermediate system. In addition, the Upgrade system includes tie-in with the weather radar in which the range/azimuth cursor intersection may be designated as a waypoint to the navigation subsystem to facilitate weather avoidance around heavy precipitation returns on the radar display. In the case of the Intermediate system, a weather avoidance waypoint may be entered from the Integrated Data Control Center (IDCC) by observing the range and azimuth to the waypoint on the radar PPI display and manually keying in the waypoint.

Growth provisions are made in PCAAS to add modules for the Discrete Address Beacon System (DABS) and the Flight Service Station (FSS) VHF Digital Data Link. DABS includes an up-link message of 8 bits representing a data command, and a down-link message of 32 bits consisting of a data identifier and parameter value. The up-link is addressed to the specific aircraft within the ATC controller's sector which assures that only returns from the addressed aircraft are displayed on the ATC ground radar display to eliminate clutter. The down-link message can be encoded with aircraft speed, altitude, magnetic heading, and other data in accordance with the message format.

The FSS VHF Digital Data Link (DDL) provision permits digital data uplink such as coded weather sequences or ATIS data to be transmitted to the aircraft for display on the IDCC display surface. The down-link message can send various standard message formats to the ground as selected from the IDCC interactive display.

Both the DABS and FSS DDL would be implemented using spare serial I/O channels on the MCC modules. The appropriate firmware would be added to the IDCC processor of the MCC complex.

ATC transponder: The ATC transponder is a 4096 code unit with altitude encoding which includes interrogation modes A and C. The King KT 78A was selected for PCAAS. This unit has a peak power output of 150 watts and includes an automatic reply light-dimmer. The transponder code may be selected from the IDCC or by backup code select knobs. The unit complies with TSO C74b, Class 2. The transponder IDENT ("squawk") function is obtained by depressing the IDENT button located on the transponder front panel.

Altitude digitizer: PCAAS utilizes an altitude digitizer which converts the altitude signal into a form suitable for the altitude encoding mode of the ATC transponder. The altitude digitizer converts a servoed altimeter pressure altitude into digital form compatible with the transponder mode C. The Aerosonic Model 1019 selected for PCAAS has an altitude range from −1000 ft to 20,000 ft. This unit uses an optical encoding method and can be remotely located from the servoed altimeter.

Weather radar: A conventional weather radar was selected for the PCAAS Intermediate system. Consideration was given to the use of the Ryan "Stormscope" which utilizes an ADF receiver and CRT to display the azimuth and amplitude of lightning strokes on a 360 deg type PPI display where stroke amplitude is coded as "pseudo range" on the display. As presently implemented, the Stormscope displays a number of previous strokes and does not vary the azimuth of these strokes as the aircraft heading changes except in the long term. The decision to use a standard weather radar was based on both functional and cost considerations. The Stormscope has the advantage of being applicable to both single engine and multi-engine aircraft. However, the use of podded weather radars or wing array antennas will permit future weather radar for the single engine aircraft.

The King KWX 40 was selected for the Intermediate system. This unit operates in X-band (9375 M Hz) and has a peak power output of 2.5 KW. The unit operates over a range of 25 to 100 N mi and covers an azimuth sector of 90 deg with a beam width of 5.6 deg. The unit is not pitch stabilized, but can be tilted ±15 deg using the manual tilt control. One disadvantage of the unit is that it uses a direct view storage tube (DVST) rather than a raster scan TV tube which limits its versatility in interfacing with digital electronics.

Radar altimeter: The radar altimeter selected for the Intermediate system is the Bonzer Mini-Mark pulse type system which has a range of 80-1000 ft with ±7 percent accuracy over this range. The unit is operable over pitch and roll attitude limits of ±30 deg. The linear analog output is converted to digital form by the Flight Sensor Microcomputer No. 3. The radar altitude is displayed digitally on the Navigation Map Display (NMD) during the approach modes and is used in the Ground Proximity Warning algorithm.

Emergency locator transmitter: The ELT has no interface with other elements of PCAAS but is an FAA required unit.

Provisions for ATC upgrade: Provision is made in PCAAS for adding elements to the system to permit upgrade to the new ATC environment as it develops. Spare serial and parallel I/O capacity is provided on the MCC circuit card modules to provide needed interfaces. Specifically provision for Discrete Address Beacon System (DABS) and Flight Service Station (FSS) Data Links is planned for PCAAS. The modular nature of PCAAS would permit other interfaces to be added as well.

<u>Flight management sensors</u>. The PCAAS utilizes a number of off-the-shelf sensors to provide the data required by the flight management functions. This information is converted to digital form (as required) by the analog to digital converter of the flight sensor microcomputer (Processor No. 3). Some of the sensors have digital output in which case the data is transformed to the parallel form required for transmission over the IEEE 488 parallel data bus.

Air speed sensor: An ideal sensor for the PCAAS airspeed sensor would be the vortex generator sensor which counts von Karman vortices shed by a small vertical wire located in a flush mounted channel perpendicular to the airflow. A turbulence sensor is located a fixed distance behind the wire vortex generator. The true airspeed (independent of temperature or pressure altitude) is proportional to the vortex rate as detected by the turbulence sensor. Each pulse measured corresponds to incremental distance travelled through the air mass corresponding to the distance between the vortex generator and the turbulence detector. Consequently, the von Karman vortex transducer has been selected for PCAAS. The true airspeed (TAS) and indicated airspeed is computed by algorithms in the flight sensor microcomputer which uses total vortex count, outside air temperature (OAT), and pressure altitude for the computation. It should be pointed out that indicated airspeed (IAS) is normally used for flying the airplane, since for a given weight the approach speed (and stall speed) is by reference to IAS rather than TAS. The TAS is used in navigation computations, however. Therefore, it is necessary to have both IAS and TAS for use in PCAAS computations and displays.

Pressure altitude sensor: The PCAAS does not require a separate pressure altitude sensor, but utilizes the remote altitude digitizer which ties into the altitude reporting transponder. The pressure altitude signal is used for a number of flight management functions including engine power computations and true airspeed computations. Pressure altitude is used in the pitch AFCS altitude hold mode. The pressure altitude signal is distributed over the IEEE 488 bus.

Manifold pressure (MP) sensor: The PCAAS MP sensor utilizes an absolute pressure transducer the output of which is converted to digital form by the ADC of Microcomputer No. 3. For turbo-charged engines the transducer must have a range of 50 in. of mercury. For conventionally aspirated engines a range of 30 in. of mercury is adequate. The manifold pressure signal is used in engine percent power computations.

Tachometer sensor: A tachometer sensor is used to measure engine revolutions per minute (rpm) which are used in engine percent power computations in conjunction with MP and outside air temperature (OAT). The tachometer has an output of pulses per second proportional to rpm which must be converted into rpm by the flight sensor microcomputer. The revolution counts are accumulated in a memory buffer located in Microcomputer No. 3.

Exhaust gas temperature sensor: The PCAAS includes an exhaust gas temperature (EGT) sensor for each cylinder of the engines. It is important to use sensors constructed of alloys which are not fouled by the hot exhaust gases. Buildup of deposits on the sensors can cause a change in calibration with time if care is not given to the sensor materials selection. The sensors selected for PCAAS are the AVICON* EGT sensors which are constructed of special nickel alloys which resist deposit buildup. The EGT sensor output is converted to digital form by the flight sensor microcomputer.

The EGT information is presented to the pilot to permit accurate leaning of the engine. The procedure recommended by AVICON is to adjust the EGT to a preset value which is selected to be some specific temperature difference below the peak EGT reading. If this temperature is approached by slowly leaning to achieve this temperature, then it will be on the rich side of the EGT peak. Alcor,† another manufacturer of EGT sensors, recommends in their sales literature that the engine be leaned to "find" the peak and then move the mixture control back toward "rich" to ensure operating on the rich side of the peak. Either procedure should achieve the same end result if carried out properly.

The EGT data is also used for the engine health monitoring function. The EGT is a sensitive, fast response, indicator of problems in the engine combustion process. The EGT trend data can detect insipient failures in the engine before they occur. The engine health monitoring function examines temperature spread among cylinders and can display abnormally cold or hot readings which may occur.

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*AVICON is located in Addison, Texas.

†Alcor is located in San Antonio, Texas.

Cylinder head temperature (CHT) is another parameter which is useful in monitoring the engine combustion process. However, since EGT and CHT tend to yield the same information regarding the engine health and since EGT is a more sensitive indicator, then CHT will not be used for PCAAS.

Fuel rate sensor: The fuel sensor selected for PCAAS is a turbine type sensor which is self-generating with an output of pulse rate proportional to flow rate. The total accumulated pulses are proportional to the total fuel consumed. Therefore, counting pulses is equivalent to measuring the fuel consumed.

Care must be exercised in installing the fuel meter in the fuel line to the engine. In some engines (e.g., fuel injection engines) a constant fuel rate is drawn from the active tank with the unused fuel returned through a return line to a given tank. For this type engine the fuel flow rate sensor must be placed in the fuel line in such a place that the net fuel rate is measured. It is possible in some installations that two fuel rate sensors may be required to measure the net fuel rate: one on the total fuel input line and one on the fuel return line with the difference between these two sensors being proportional to the net fuel rate.

Inertial sensors.-The inertial sensors are required to provide aircraft attitude and rate information used for instrument flight display and for automatic flight control system stabilization and control signals. The output of the inertial sensors is converted to appropriate digital form in the flight sensor microcomputer. The inertial sensors are also used to drive the ADI and HSI displays.

A number of low-cost alternatives to the inertial sensors were considered for PCAAS. However, the selections made represent a low risk approach. The potential cost savings of nonconventional instrument plus digital processor approaches to measure the aircraft state vector deserve continuing consideration for the General Aviation Advanced Avionics Program.

Magnetic heading sensor: A directional gyro was selected to provide magnetic heading. This gyro is slaved to a magnetic compass at a rate of 2 deg/minute. The NARCO HSI 100S was selected for PCAAS. Consideration was given to using a two-axis strap-down magnetometer with computation to compensate for turning errors and variations in the vertical component of the earth's magnetic field. The magnetometer approach has the potential for lower cost but has problems of pilot acceptance as a primary source for heading reference.

Attitude gyro: A conventional attitude gyro is provided for roll and pitch attitude signals. This gyro drives the Attitude Director Indicator (ADI). The pitch and roll attitude signals are also directed to the flight sensor microcomputer where they are converted to the required digital format.

Yaw rate gyro: The yaw rate gyro is provided as a stabilization signal if the directional stability of the basic airplane is inadequate.

Integrated Data Control Center.-The IDCC is illustrated and functionally described in the subsection entitled "Automatic Flight Control System Functions." The IDCC utilizes a CRT display surface with a keyboard for entering data and selecting functions and modes. One processor of the Microcomputer Control Complex (Microcomputer No. 3) is dedicated to the IDCC. The MCC includes a CRT/keyboard interface module which provides for decoding up to 128 key inputs and for providing the IDCC raster scan display refresh and character generation.

An RS 232C serial interface is provided for transfer of data between the tape cartridge mass memory and the IDCC data memory.

Navigation Map Display. The NMD is illustrated and functionally described in the subsection entitled "Navigation Map Display." The NMD utilizes the MCC Microcomputer No. 4 for performing the necessary computations and data handling. The NMD microcomputer includes a CRT/keyboard module for interfacing with the CRT and the mode selection switches of the NMD. The NMD may also interface with the data base on the tape cartridge mass memory through an RS 232C serial data interface.

Microcomputer Control Complex

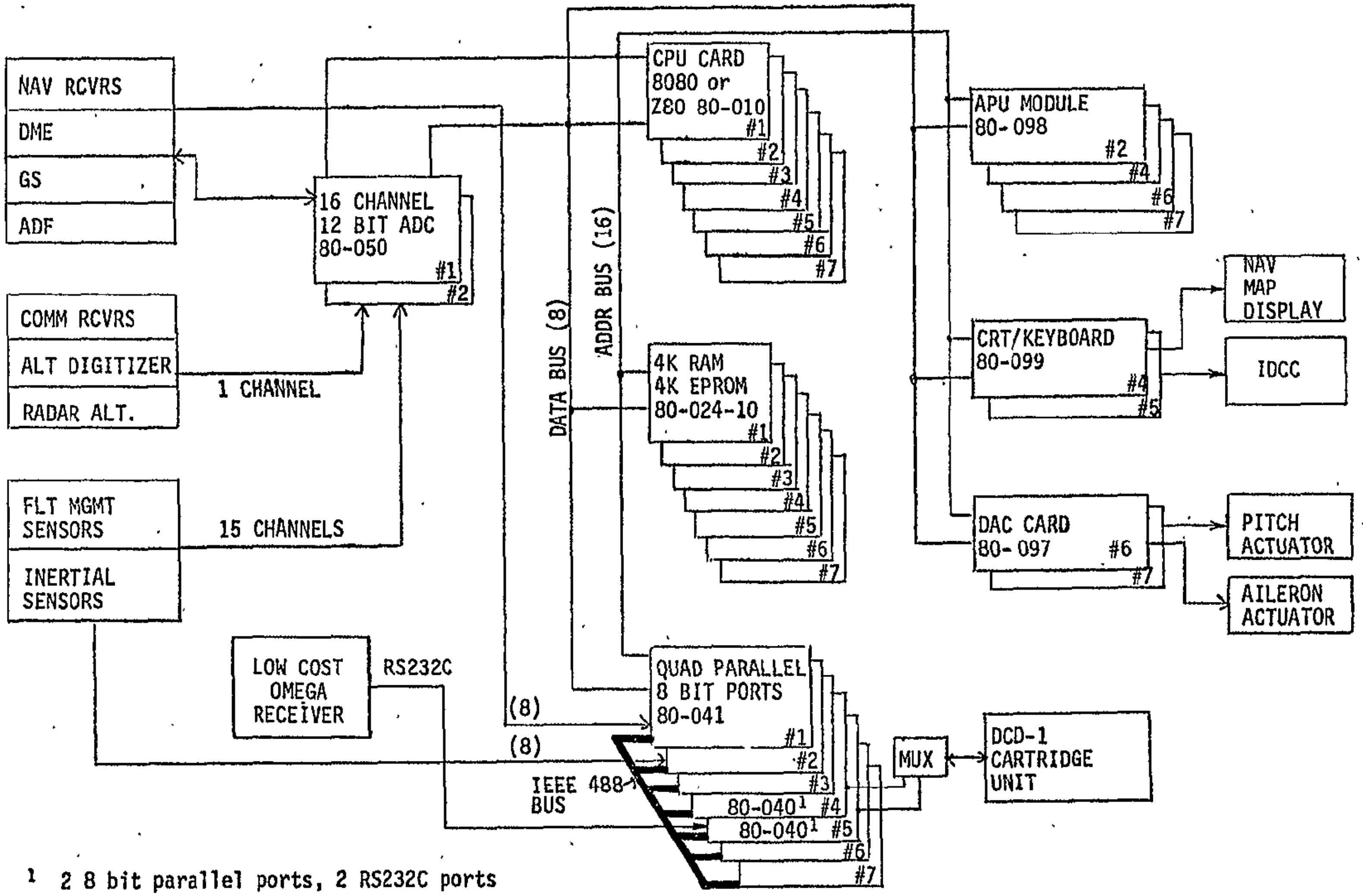
The MCC is shown in Fig. 13 which is organized into 7 separate microcomputers performing the following functions:

- Frequency management and navigation radio interface
- General navigation computations
- Flight sensor data management and interface
- Navigation map computations
- IDCC data handling and computations
- Lateral AFCS equations and interface
- Pitch AFCS equations and interface

The 7 processors communicate with one another using the IEEE 488 external data bus which consists of 8 bits of data and 8 bits of status and command. Care has been taken in allocating functions among the seven microcomputers to require only relatively slow data to be transmitted between microcomputers. The data rates on the IEEE 488 bus are summarized in Table 6.

MCC block diagram.-The MCC block diagram shown in Fig. 13 displays the standard modules used in the MCC implementation. Figure 13 shows the internal 8 bit data bus and 16 bit address bus as well as the external 16 bit IEEE 488 data bus. The reader should note that the internal buses are actually separated in accordance with the seven MCC processors with the modules numbered in accordance with the CPU module numbers. For example, Microcomputer No. 1 includes a 16 channel 12 bit ADC card (80-050), a CPU card (80-010), a 4 K RAM/4 K EPROM card (80-024-10), and a quad parallel I/O card (80-041).

The data carried on the IEEE 488 bus and the preliminary data rates are summarized in Table 6. The preliminary estimate of the total data rate on the line is only 685 bytes/sec which represents a very small percentage of the data rate capacity of the bus, which is approximately 1 megabyte/sec.



[1] 2 8 bit parallel ports, 2 RS232C ports

Figure 13. PCAAS Microcomputer Control Complex (MCC)

TABLE 6

PCAAS DATA RATES ON IEEE 488 BUS

SIGNAL	SOURCE	DESTINATION	NO. BYTES	DATA RATE
VOR/LOC #1 ERROR	NAV RADIO #1	NAV COMPUTER	2	1/SEC
VOR/LOC #2 ERROR	NAV RADIO #2	"	2	"
DME DISTANCE	DME #1	"	3	"
GS ERROR	GS #1	"	2	"
ADF BEARING	ADF #1	"	3	"
OMEGA POSITION	OMEGA NAV SET	"	10	1/4 SEC
PRESS ALTITUDE	ALT DIGITIZER	"	4	1/SEC
NAV #1 FREQ CMD	IDCC	FREQ MGMT COMP	2	"
NAV #2 " "	"	"	2	"
COMM #1 " "	"	"	3	"
COMM #2 " "	"	"	3	"
RADAR ALTITUDE	RADAR ALTIMETER	NAV COMP/IDCC	3	10/SEC
IAS	FLT SENSOR DATA COMP	"	3	1/SEC
OAT	"	"	3	"

TABLE 6 (CONCLUDED)

SIGNAL	SOURCE	DESTINATION	NO. BYTES	DATA RATE
MANIFOLD PRESSURE	FLT SENSOR DATA COMP	IDCC	2	1/SEC
RPM	"	"	2	"
EGT	"	"	2	"
FUEL FLOW RATE	"	"	3	"
DIRECTIONAL GYRO	"	"	3	40/SEC
PITCH ATTITUDE	"	"	3	"
ROLL ATTITUDE	"	"	3	"
YAW RATE	"	"	2	"
AFCS MODE	IDCC	AFCS	2	1/SEC
AFCS CMD	NAV COMP	"	6	10/SEC
AIRCRAFT POSITION	"	IDCC/NAV MAP DISPLAY	10	1/SEC
NAV CORRELATION	"	IDCC	2	"
AIRCRAFT HDG & SPEED	"	IDCC/NAV MAP DISPLAY	6	10/SEC
		TOTAL DATA RATE		685 BYTES/SEC

The estimated cost of the MCC hardware is estimated to be $6,975 as shown in the breakdown in Table 7. This cost does not include non-recurring engineering for packaging the system or for the software development costs. However, the MCC uses largely off-the-shelf (OTS) modules installed in an OTS card cage which includes a backplane circuit board (mother board). The dimensions of the total MCC package are 4.6" x 6.6" x 1.5" and weighs 20.8 pounds.

The memory allocation for MCC microcomputers is shown in Table 8 for each of the 7 processors. The total data memory (RAM) is estimated to be 17 K bytes. The total program memory which utilizes ultraviolet Erasable Programmable Read Only Memory (EPROM) is 18 K bytes. The memory to be used will be sufficiently fast to use microprocessors with higher clock rates than the standard 8080. For example, the Z-80, which is downward compatible with the 8080, uses a 2.5 M Hz clock. The option of using either the 8080 or Z-80 is open.

Standard modules.-Standard circuit modules are used for PCAAS MCC in order to reduce the non-recurring cost. The advantage of using the 8080 family of microprocessor chips is that there is a wide selection of standard modules to implement the required functions. Small size circuit cards which are 3.8" x 6.5" were selected for PCAAS. These cards are available from muPRO, Inc., located in Sunnyvale, California. The standard card cage complete with motherboard is 4.25" high by 7.6" wide by 15" deep. The standard modules are described below.

CPU card (P/N 80-010): Seven CPU cards are required for the Intermediate system. The CPU card has the following features:

- Buffered data, address, status, control lines
- Crystal oscillator 350 NS period
- Direct interface to static RAM's and PROM's
- Eight-level vectored priority interrupt
- All status/control functions available for complete system design flexibility

TABLE 7

MCC COST SUMMARY

CARD NAME	PART NO.	QTY	UNIT COST	EXTENDED COST
CPU	80-010	7	$240	$1,680
QUAD PARALLEL I/O	80-041	5	225	1,125
PERIPHERAL I/O	80-040	2	290	580
16 CHANNEL 12 BIT ADC	80-050	2	300	600
4K RAM/4K EPROM WITH 1K RAM	80-024-10	7	200	1,400
EPROMs	2708	18	40	720
RAMs	4K x 1	8	652	50
CARD CAGE		1	450	450
POWER SUPPLY		1	160	160
CHASSY ASSEMBLY		1	125	125
CABLES		1 LOT	85	85
			TOTAL	$6,975

DIMENSIONS: 4.6" x 6.6" x 15"

TABLE 8

MCC MEMORY ALLOCATION

MICROCOMPUTER	DATA RAM	PROGRAM EPROM
Frequency Management (No. 1)	1K	1K
Navigation (No. 2)	4K	4K
Flight Management Sensors (No. 3)	2K	1K
Navigation Map (No. 4)	4K	4K
IDCC (No. 5)	4K	4K
Lateral AFCS (No. 6)	1K	2K
Pitch AFCS (No. 7)	1K	2K
	17K bytes	18K bytes

- Power-on reset circuitry
- On-card regulators for +12V and −5V
- Power requirements: +5V @ 940 mA
  +15V to +18V @ 65 mA
  −15V to −18V @ 45 mA
- Physical: 3.8" H x 6.5" W
- Environmental
  - Temperature: Operating: 0° C to 50° C
    Non-operating: −20° C to 65° C
  - Humidity: 5 to 95 percent (noncondensing)

Note: All modules have the same physical and environmental characteristics as the CPU module.

4 K RAM/4 K EPROM module (80-024-10): Each of the 7 MCC microcomputers uses a 4 K RAM/4 K EPROM module to provide both the data memory and program memory required for each processor. The board is populated with sufficient RAM chips and EPROM chips to provide the memory allocations summarized in Table 8. The memory modules have the following features:

- Address and data bus buffering
- On-card address selection
- On-card regulators for +12V and −5V
- Memory organization: 4096 x 8 PROM
  4096 x 8 RAM
  (May be populated in increments of 1 K bytes of 2708 PROM and 1 K bytes of static RAM.)
- Access/cycle time — PROM and RAM: 450 nS
- Power requirements: +5V @ 500 mA
  +15V to +18V @ 150 mA
  −15V to −18V @ 110 mA

In the event more RAM or more EPROM is required, there are alternate memory cards which provide more memory on a single card. For example, there is an 8 K EPROM board which provides space for eight 1 K by eight 2708 EPROMS.

Quad parallel I/O card (80-041): The MCC uses five of these quad parallel I/O cards. Each card has two 8255A Programmable Peripheral Interface (PPI) chips. Each PPI has 24 bits of I/O which can be programmed in three major modes: (1) each group of four pins can be programmed as input or output, (2) each group of eight pins can be programmed as input or output, and (3) eight lines for a bidirectional bus and five lines for handshaking and interrupt control are provided.

The quad parallel card is used for the IEEE 488 bus interface as well as other parallel I/O requirements. The features of the quad parallel card are

- Forty-eight programmable I/O lines
- Two 8 bit ports capable of bidirectional data transfer
- User selectable driver and termination options
- I/O device or memory mapped operation
- Interrupt driven or software timed data transfer
- I/O modes: all 8255 I/O modes
- Addressing
  - I/O device: occupies eight consecutive I/O device codes (jumper selectable)
  - Memory mapped: occupies a 2 K byte block of memory (jumper selectable)
- Interrupts: priority level independently selectable for each 8255 function
- Power requirements: +5V @ 800 mA (nominal without terminations)

Peripheral interface card (80-040): Two peripheral interface cards are used for Processors No. 4 and No. 5. Each card has 2 serial interfaces and two 8 bit parallel interfaces with handshake capability. The card uses 2 programmable communication interface (PCI) chips (8251) for the serial I/O and one 8255 PPI chip for the dual 8 bit parallel ports. An on-card crystal controlled baud rate generator provides a number of serial baud rates which are jumper selectable.

The serial ports are used to interface with the tape cartridge. The parallel ports provide the IEEE 488 bus interface. The features of the card are summarized as follows:

- Two serial interfaces
- RS-232C or 20 mA current loop
- Selectable crystal-controlled baud rates
- Two 8 bit parallel interfaces with handshake
- I/O device or memory mapped operation
- Interrupt driven or software timed data transfer
- On-card regulators for +12V and −12V
- Parallel I/O functions: two 8 bit parallel ports with handshake and two auxiliary controls (8255 mode 1)
- Serial I/O functions: two serial RS-232C or 20 mA current loop ports (8251) with independently programmable baud rates: 27.5, 37.5, 45, 75, 110, 150, 300, 600, 1200, 1760, 1800, 2400, 2880, 4800, 9600, 19200, and 38400.
- Addressing
  - I/O device: occupies eight consecutive I/O device codes (jumper selectable)
  - Memory mapped: occupies a 2 K byte block of memory (jumper selectable)
- Interrupts: priority level independently selectable for each serial and parallel port
- Power requirements: +5V @ 825 mA
+15V to +18V @ 20 mA
−15V to −18V @ 10 mA

Sixteen channel, twelve bit ADC card: The MCC uses two of the analog to digital converter (ADC) cards for Processors No. 1 and No. 2 for converting sensor signals to digital form. The characteristics of these cards are summarized below:

- Twelve bit resolution
- ±0.025 percent accuracy
- Sixteen single-ended or eight differential channels
- Selectable input gain or 1, 10, or 100
- Sample-and-hold
- Forty microsecond conversion speed (maximum)
- User selectable unipolar or bipolar full scale range
- Unsigned binary or 2s complement with sign extension data formats
- User selectable conversion rate and sampling time
- Software channel selection or automatic n-channel scan mode
- On-card buffer memory
- Input impedance: 100 M ohm resistive (without terminations)
  10 pF Off channel
  30 pF On channel
- Input signal ranges (gain = 1): −10V to +10V
  −5V to +5V
  −2.5V to +2.5V
  0V to +10V
  0V to +5V
- Accuracy
  - Offset error: adjustable to zero
  - Linearity: ±1/2 LSB
  - Quantizing error: ±1/2 LSB
  - Overall system accuracy: ±0.025 percent of full scale
- Conversion characteristics
  - Sample-and-hold acquisition time: user selectable N × (7 μsec)
  - Aperture time: 150 nS
  - Conversion speed: user selectable N × (20 μsec) per channel. Note: N = 2 to 16

- Channel selection
  - Mode 1: channel selection and channel sequence software controlled
  - Mode 2: channel 1 through X (up to 16) scanned sequentially, with highest channel number (X) software selectable. Optional interrupt after each scan
- Power requirements: +5V @ 640 mA
  +15V to +18V @ 40 mA
  −15V to −18V @ 40 mA

Digital to analog converter card (80-09?): The digital to analog converter card utilizes a 12 bit binary digital to analog converter chip (the National DA 1200 chip). Two of these cards are used by the MCC, one for Processor No. 6 and one for Processor No. 7, to provide a signal level input to the pitch actuator and aileron actuators. The features of the DA 1200 chip are summarized below:

- Circuit completely self-contained
- Both current and voltage-mode outputs
- Standard power supplies: ±15V and +5V
- Internal reference: 10.24V for binary
  10.00V for BCD
- 0 to 2 mA, ±10V or 0 to 10V output by strapping internal resistors; other scales by external resistors
- ±1/2 LSB (binary) or ±1/10 LSD (BCD) linearity
- Fast settling time: 1.5 μsec in current mode
  2.5 μsec in voltage mode
- TTL and CMOS compatible complementary binary or BCD input logic format
- Twelve bits, expandable to fourteen or sixteen bits

CRT/keyboard card (80-099): The MCC employs two of the CRT/keyboard cards, one for the NMD and one for the IDCC. These cards provide the CRT interface and the keyboard strobing interface for both the NMD and IDCC.

The cards utilize the 8275 programmable CRT controller (PCC) chip and the 8279 programmable keyboard/display interface (PKDI) chip.

The 8275 programmable CRT controller is a single chip device designed to interface CRT raster scan displays with the 8080 Microcomputer System. Its primary function is to refresh the display by buffering the information from main memory and keeping track of the display position of the screen. The flexibility designed into the 8275 will allow simple interface to the raster scan display with a minimum of external hardware and software overhead. The 8275 interface diagram is shown in Fig. 14.

The features of the 8275 are as follows:

- Programmable screen and character formats
- Six independent visual field attributes
- Eleven visual character attributes (graphic capability)
- Cursor control (four types)
- Light pen detection and register
- Dual row buffers
- Programmable DMA burst mode
- Single +5V supply
- Forty pin package

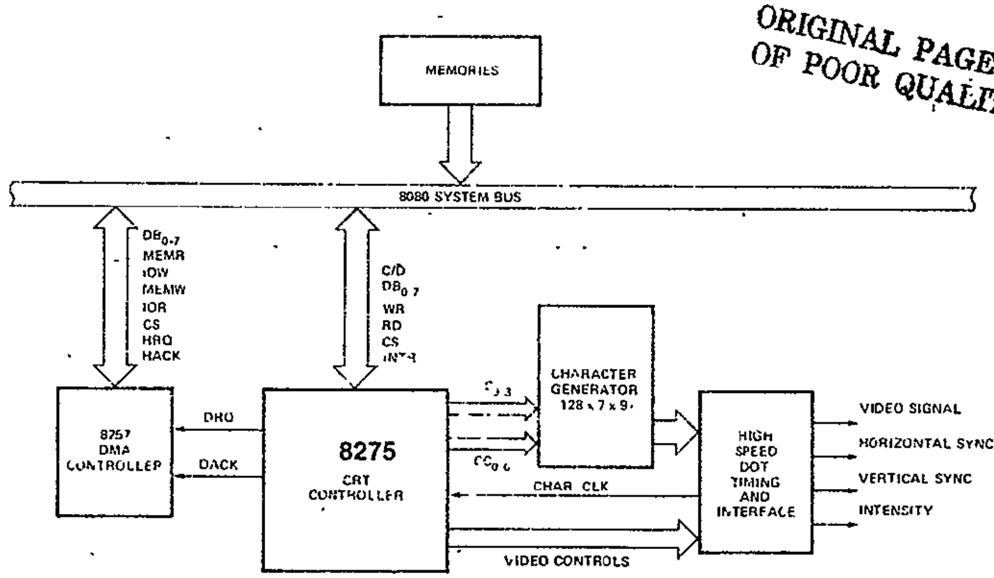


Figure 14. The 8275 Interface Diagram

The block diagram for the programmable keyboard/display interface (PKDI) chip is shown in Fig. 15.

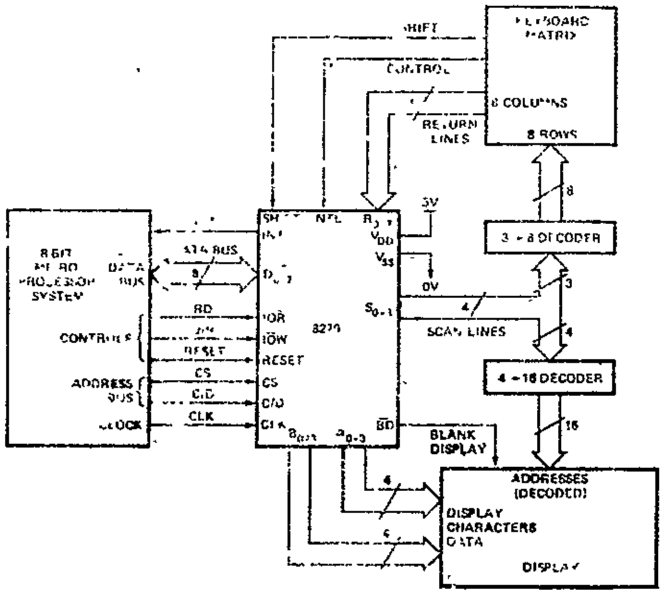


Figure 15. 8279 PKDI Chip

The 8279 is a general purpose programmable keyboard and display I/O interface device designed for use with microprocessors. The keyboard portion can provide a scanned interface to a 64 contact key matrix which can be expanded to 128. The keyboard portion will also interface to an array of sensors or a strobed interface keyboard such as the Hall effect and Ferrite variety. Key depressions can be 2 key or N key rollover. Keyboard entries are debounced and stored in an eight character first in first out register (FIFO). If more than eight characters are entered, overrun status is set. Key entries set the interrup output line to the CPU.

Arithmetic processor unit (APU) module: The arithmetic processor unit (APU) module is used by those MCC processors which have considerable arithmetic computations, particularly trignometric functions and multipliers. The APU modules are used for the Navigation Processor (No. 2), the Navigation Map Display Processor (No. 4), and the two AFCS Processors (No. 6 and No. 7).

The APU module utilizes the Am 9511 chip and the 8238 system controller and bus driver chip for interfacing with the 8080 CPU module. The APU provides processing of arithmetic functions in parallel with the CPU, thereby greatly increasing the MCC throughput. The availability of the APU chip makes use of an 8 bit microprocessor (the 8080A) for the PCAAS MCC feasible. Otherwise certain of the MCC processors would require a 16 bit microprocessor to achieve adequate throughput for the MCC computation functions. Figure 16 illustrates the APU concept. The 8080 CPU issues an operand and a command to execute an arithmetic function to the 9511 APU. The APU computes the function, issues an interrupt to the 8080 CPU telling it that the answer is ready.

There is some overhead associated with the 8080 CPU setup time and answer retrieval. However, the net result is arithmetic functions being executed 100 to 200 times faster than software.

The features of the Am 9511 APU are summarized below:

- Performance advantage of 100-200 times over software
- Execution overlapped with CPU processing
- Single/double precision (16/32 bit) fixed-point arithmetic (add, sub, mul, div)
- Floating-point basic functions (add, sub, mul, div)
- Floating-point trigonometric functions (32 bit) (including inverse functions)
- Floating-point exponential, logarithm (32 bit) powers and roots
- Format conversion commands
- Data manipulation commands
- Reverse Polish data/command entry sequence
- General purpose 8 bit data bus interface
- Designed to work in systems that use polled status, interrupt, or DMA functions

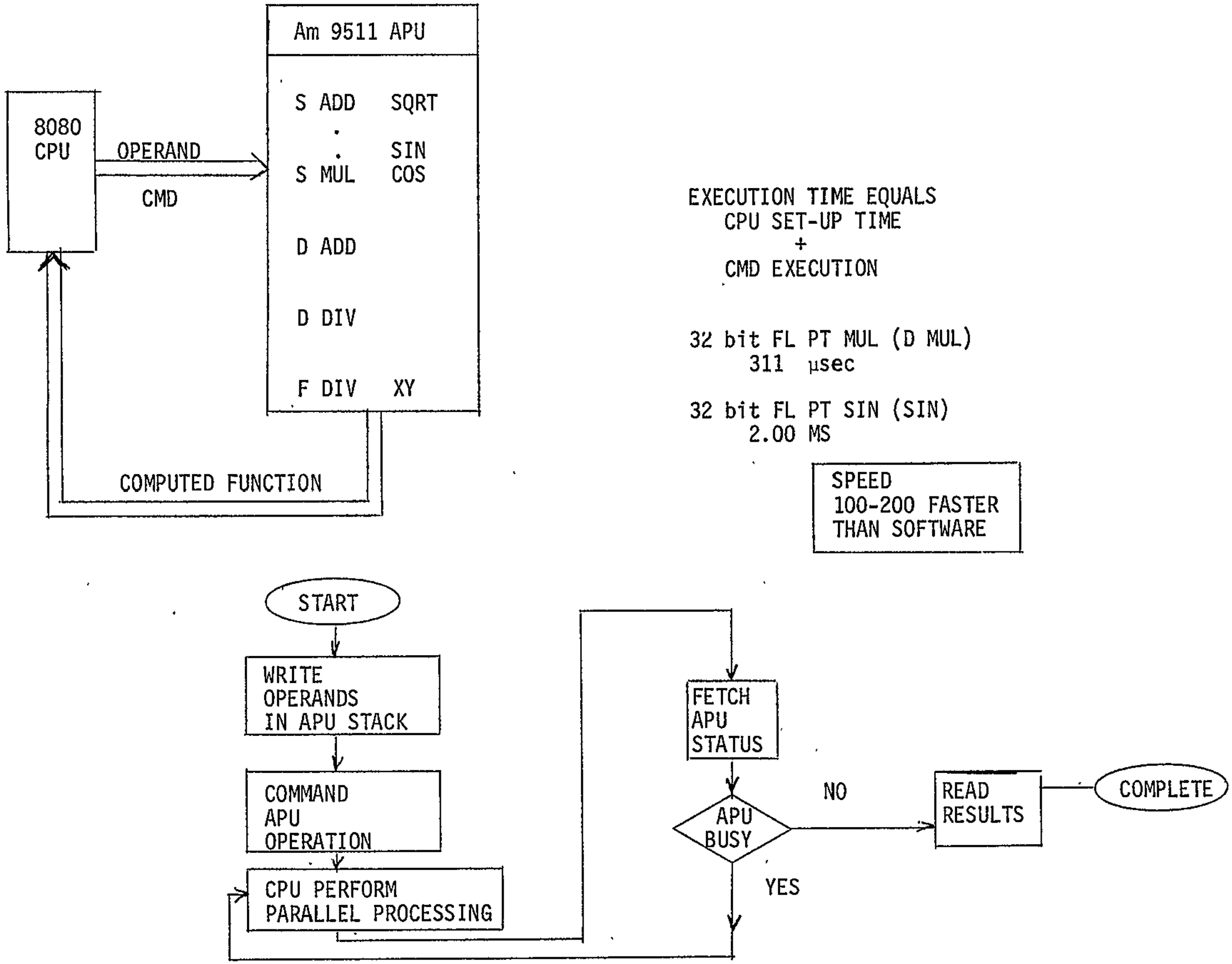


Figure 16. Arithmetic Processor Unit Concept

The APU interface with the 8080 CPU through the 8238 system controller and bus driver is shown in Fig. 17. The Am 9511 APU arithmetic commands are tabulated in Table 9. SADD means single precision (16 bit) fixed-point add. DADD means double precision (32 bit) fixed-point add. FADD means floating point (32 bit) add. All of the transcendental functions (i.e., SQRT, SIN, COS, etc.) are 32 bit floating point.

Data cartridge mass memory: The PCAAS utilizes a data cartridge mass memory which has a 100 K byte storage capacity. This memory unit is physically packaged with the IDCC panel for access to the minicartridge which holds the data on magnetic tape. Figure 18 shows the data cartridge drive unit (DCD-1) and the minicartridge (DC 100A). The characteristics of the DCD-1 data cartridge drive unit are presented in Table 10.

IEEE 488 external bus interface.-The IEEE 488 digital interface was devised for programmable instrumentation devices and consists of a 16 bit bus of which 8 bits are for data and 8 bits are for addressing and handshake functions. A single bus is used in the PCAAS MCC for communicating among the seven processors of the Intermediate system. A redundant bus is not required for PCAAS because no flight critical or flight safety items are carried on the bus. Redundant and backup means are provided for the flight critical functions of communication and navigation in the event the bus should suffer a failure. Care is taken in the interface circuit design to prevent component failures from eliminating the complete bus.

The details of the bus structure are presented in Fig. 19.

MCC software (firmware).-The Microcomputer Control Complex (MCC) software will be resident in Erasable Programmable Read Only Memory (EPROM's) which is referred to as "firmware." The distributed architecture of the MCC imposes a modular software approach for PCAAS. The principal software modules are described in the subsections below.

Frequency Management Microcomputer No. 1 software: The Frequency Management microcomputer software includes the following routines:

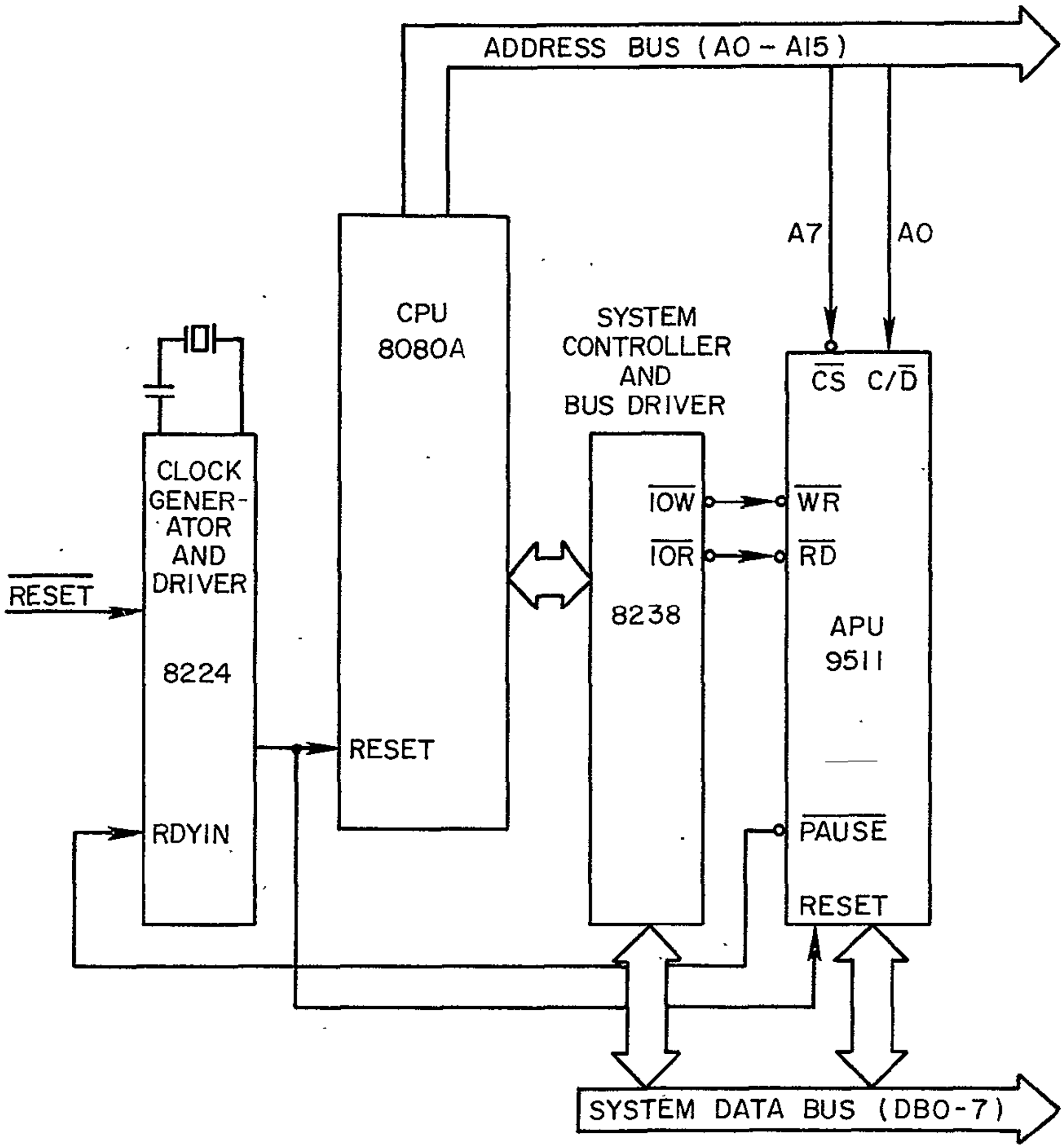


Figure 17. Am9511 APU Interface

TABLE 9

Am 9511 INSTRUCTION SET ARITHMETIC COMMANDS

INSTRUCTION	TIME*	INSTRUCTION	TIME*
SADD	8.0	SQRT	322
SSUB	13.0	SIN	1882
SMUL	41.0	COS	1856
SDIV	43.0	TAN	2408
DADD	10.0	SIN^{-1}	3038
DSUB	19.0	COS^{-1}	3151
DMUL	69.0	TAN^{-1}	2492
DDIV	69.0	ln	1908
FADD	28-168	e^x	1955
FSUB	35-169	LOG_{10}	1968
FMUL	57.0	X^Y	3863
FDIV	57.0		

*NOTE: All times are given in microseconds with 2 M Hz clock input.

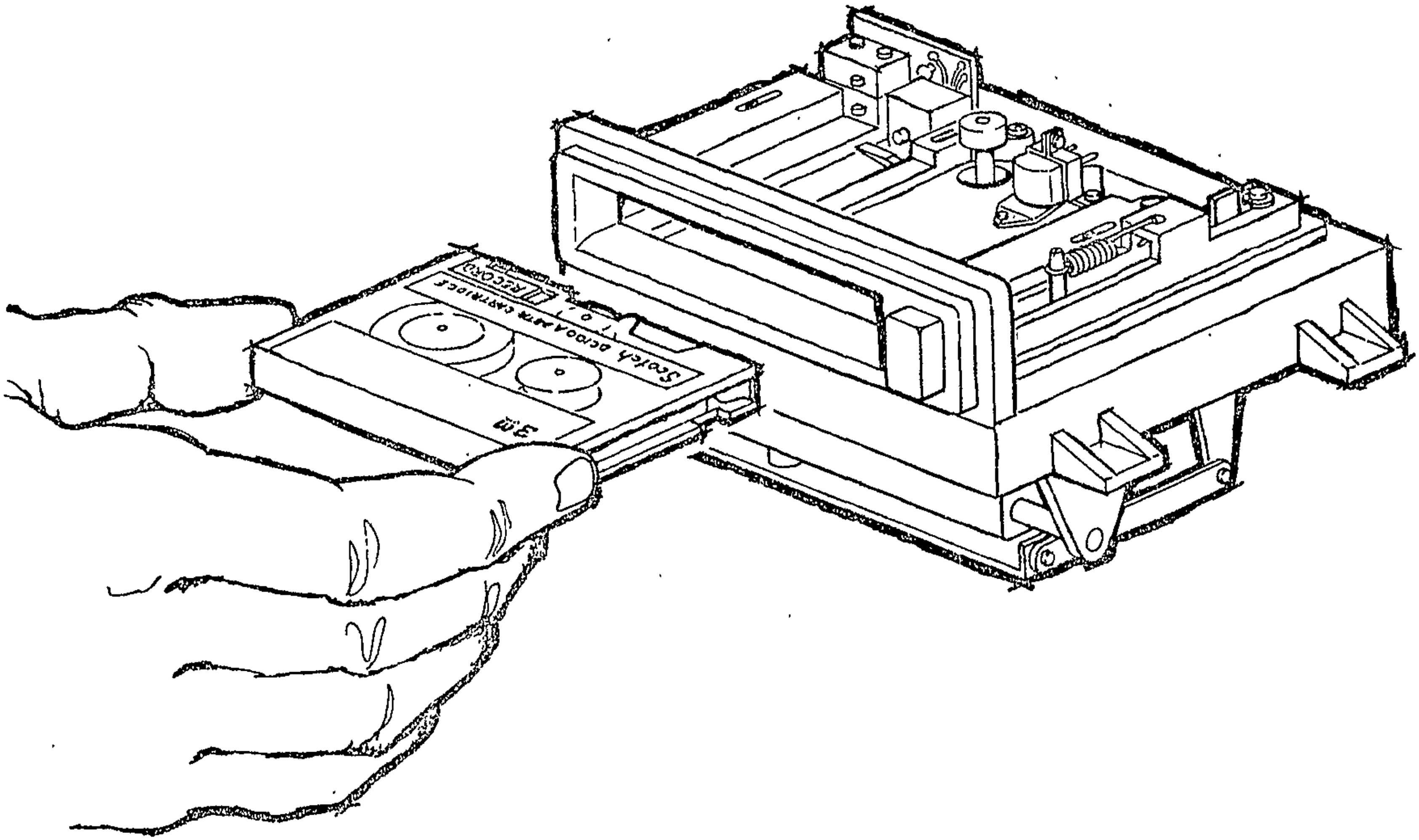


Figure 18. DC100A Data Cartridge and DCD-1 Data Cartridge Drive

TABLE 11

DCD-1 DATA CARTRIDGE DRIVE

Cartridge:	Uses the "Scotch" Brand DC100A Data Cartridge
Speed:	30 IPS (76.2 cm/sec) forward; 30 IPS (76.2 cm/sec) or 60 IPS (152.4 cm/sec) reverse (factory set)
Average Transfer Rate:	2530 bytes/sec (formatted)
Data Capacity:	100,000 bytes, average
Interrecord Gap Length:	1 inch (2.54 cm) nominal
Start Delay:	27 milliseconds
Stop Delay:	5 milliseconds
Tape Head:	Single channel, single gap, full width
Interface Logic:	TTL compatible
Power:	+5VDC ± 5%, 1.5 amps +12VDC (+10.8 to +15VDC), 3.0 amps peak, 1 amp average
Ambient Temperature:	0°C to 50°C
Relative Humiditv:	20% to 80% noncondensing
Duty Cycle:	7 start/stop operations per second, maximum
Size:	Drive 5 in. wide (12.7 cm) 4 in. high (10.2 cm) 4½ in. deep (11.4 cm) Electronics Two 5 in. x 12 in. cards (12.7 x 30.48 cm)
Weight:	3¼ pounds max. (1.47 kg)
Finish:	All metal surfaces finished per best commercial practices.

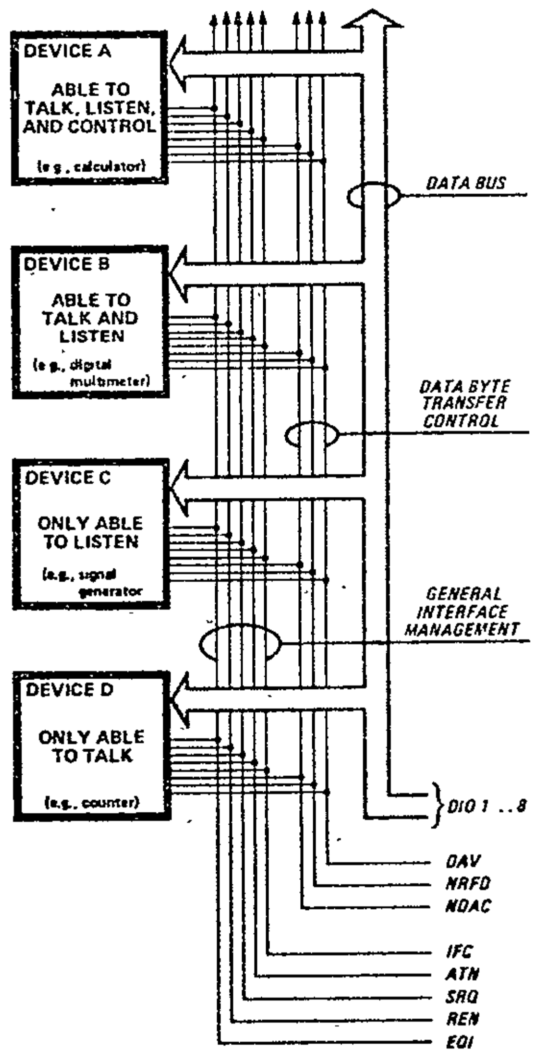


Figure 19. Interface Capabilities and Bus Structure

- Issues frequency commands to the VOR navigation receivers, the communication transceivers, and the transponder.

- Performs frequency tuning of dual VOR receivers for area navigation, using "best geometry" stations with tuning performed by an algorithm.

- Performs single VOR receiver frequency hopping for single receiver operations.

- Inputs VOR bearing measurements, DME distance, and ILS errors and formats data for IEEE 488 bus.

- Acts as "listener" and "talker" on IEEE 488 bus. "Listens" for frequency commands, "talks" of VOR radials, DME distance, localizer error, and glide slope error.

- Performs self-test functions.

Navigation Microcomputer No. 2 software: The Navigation Microcomputer performs the computation and mode logic associated with the general navigation function of the PCAAS. The Navigation Microcomputer software includes the following routines:

- Computes best estimate of present position in latitude and longitude coordinates by combining position in a Kalman Filter sense from the following sources:

  - OMEGA δLAT, δLNG
  - ρ/θ RNAV from VOR/DME
  - ρ/ρ RNAV from MUX DME
  - θ/θ RNAV from Dual VOR
  - θ/θ RNAV from MUX VOR

  This routine includes the logic which selects the optimum set of position data sources.

- Derives present position from initial LAT/LNG and updates by dead reckoning computation. The DR position is updated at a slow rate (once every 40 sec) by the Kalman Filter best estimate.

- Computes range and bearing to selected waypoints. Calculates ground speed relative to the selected waypoint.

- Computes wind direction and speed.

- Issues commands to arithmetic processor unit for computation of arithmetic and transcendental functions and receives computed function values.

- Acts as listener and talker on IEEE 488 bus. Acts as backup controller to IDCC microcomputer.

- Performs correlation on navigation position for flight status correlation function.

- Computer vertical navigation trajectories and determines VNAV error signals.

- Computes RNAV error signals.

- Issues guidance commands via IEEE 499 bus to lateral AFCS microcomputer including:
  - RNAV intercept/coupling
  - VOR intercept/coupling
  - LOC intercept/coupling

- Issues guidance commands via IEEE 488 bus to pitch (longitudinal) AFCS microcomputer including:
  - VNAV intercept/coupling
  - GS intercept coupling

Flight Sensor Microcomputer No. 3 software: The Flight Sensor Microcomputer performs various computations associated with the flight sensors and performs certain flight management functions. The Flight Sensor Microcomputer software includes the following routines:

- Performs analog to digital signal conversions on flight management sensors and formats the digital data.

- Computes true airspeed from IAS, OAT, and pressure altitude.

- Computes engine horsepower being developed as a function of manifold pressure, rpm, OAT, and pressure altitude by means of look-up tables.

- Issues "leaning commands" to pilot display based upon EGT measurements made on each cylinder.

- Issues throttle setting commands to achieve selected horsepower or for best range based upon selected rpm and using measured pressure altitudes and OAT.

- Implements Ground Proximity Warning algorithm and issues warning on IEEE 488 bus for display on IDCC and for aural warning.

- Inputs digital pressure altitude signal and formats for IEEE 488 bus.

- Receives input from fuel rate sensor and computes amount of fuel used. Formats data for 488 bus.

- Performs analog to digital signal conversion on inertial sensors and format the digital data for the 488 bus.

- Acts as listener and talker on IEEE 488 bus.

Navigation Map Microcomputer No. 4 software: The NMD Microcomputer provides for displaying navigation map data and aircraft position on a CRT surface for pilot orientation. The NMD has a number of modes including en route map, area map, approach, and HSI. The latter mode is used to provide lateral guidance for manual flight.

The NMD software includes the following routines:

- Access of navigation data base from data cartridge and transfer to data memory in the microcomputer through a serial port.

- Acts as "listener" and "talker" on IEEE 488 bus.

- Provides CRT interface functions including refresh and symbol generation via commands to the 8275 CRT controller chip.

- Implements logic and computation for the various NMD modes and responds to mode selection logic.

- Accepts and displays coordinates from IEEE 488 data bus from navigation computer for display.

- Accepts and displays magnetic heading for heading indicator display.

- Issues commands to APU and receives computed functions from APU.

Integrated Data Control Center Microcomputer No. 5 software: The IDCC microcomputer provides most functions and mode selections for the PCAAS except for the AFCS and frequency select which are dedicated control panels. The IDCC software includes the following routines:

- Responds to the keyboard inputs via programs to the 8279 PKDI chip on the CRT/keyboard card.
- Provides interface commands to the CRT via programs to the 8275 CRT controller chip.
- Implements all mode selection logic and displays selection "menus" on CRT display.
- Acts as principal controller for IEEE 488 bus and also acts as "listener" and "talker" on 488 bus.
- Access of data base from the data cartridge mass memory.

Lateral AFCS Microcomputer No. 6 software: The Lateral AFCS Microcomputer provides the computations associated with the lateral autopilot modes. The Lateral AFCS software includes the following routines:

- Receives lateral guidance commands, inertial sensor data, and flight sensor data over the IEEE 488 data bus. Receives mode selection from AFCS model select panel.
- Issues commands to APU and receives computed functions.
- Implements following lateral AFCS modes:
  - Yaw augmentation
  - Turn rate command
  - Hold/set heading
  - Respond to lateral guidance commands for RNAV and localizer
- Sends command to aileron actuator via digital to analog converter.
- Normalize inner loop gain as function of IAS.
- Provides outer loop gain changes for various lateral modes.

Longitudinal (Pitch) AFCS Microcomputer No. 7 software: The Longitudal (Pitch) AFCS Microcomputer provides the computations associated with the pitch autopilot modes. The longitudinal AFCS software includes the following routines:

- Receives the longitudinal guidance commands, inertial sensor data, and flight sensor data over the IEEE 488 bus. Receives mode selection from AFCS mode select panel.
- Issues commands to the APU and receives computed functions.
- Implements the following longitudinal AFCS modes:
  - Phugoid damping from normal accelerometer
  - Hold pitch attitude
  - Hold pressure altitude
  - Hold IAS
  - Respond to pitch guidance commands for VNAV and glide slope
  - Pitch support signal during lateral turns
- Sends commands to the elevator actuator via the DAC module.
- Normalize inner loop gain as function of IAS.
- Provide outer loop gain changes for various pitch modes.

Software functional redundancy: The purpose of software functional redundancy is to provide backup of primary software functions in the event of a microcomputer processor failure. Since no flight safety items are implemented in the MCC without providing manual backup, the functional redundancy is not a flight critical or flight safety item.

The software functional redundancy provided is summarized in Table 12.

System Modularity

The PCAAS system mechanization features system modularity to permit transitioning from current avionics systems to PCAAS, and to permit adding or deleting functions to cover the spectrum of general aviation aircraft.

TABLE 12. SOFTWARE FUNCTIONAL REDUNDANCY

REDUNDANT SOFTWARE ROUTINES	FREQ MGMT µCOMP #1	NAV µCOMP #2	FLT SENSOR µCOMP #3	NAV MAP µCOMP #4	IDCC µCOMP #5	LATERAL AFCS µCOMP #6	LONGIT AFCS µCOMP #7
● SELF TEST	Primary		Back-up				
● ρ/θ RNAV	Back-up	Primary					
● Dead Reckoning		Primary	Back-up				
● Computes Leaning Cmd	Back-up		Primary				
● GPW	Back-up		Primary				
● NAV MAP HSI Mode				Primary	Back-up		
● NAV MAP Approach Mode				Primary	Back-up		
● Emergency Checklists				Back-up	Primary		
● Mode Selection Display				Back-up	Primary		
● IEEE 488 Bus Controller		Back-up			Primary		
● Turn Rate Command						Primary	Back-up
● Hold Heading						Primary	Back-up
● Hold Altitude						Back-up	Primary

The PCAAS modularity assumes the following forms:

- Avionics equipment elements may be added to or deleted from the Intermediate system list.
- A particular avionic element may be exchanged for an upgraded or downgraded element.
- Modes may be added to or deleted from the Intermediate mode list by modifying the software (firmware) of the IDCC microcomputer.
- Software (firmware) required for new functions is added to the appropriate processor.
- Spare I/O capacity is used for new functions added. Or a new I/O board may be added to spare card slots in the MCC in the event spare I/O is not available.

The modularity characteristics of PCAAS are illustrated in Table 12 which shows the changes in avionic elements from the Intermediate system to achieve the Basic system or the Upgrade system. Elements are deleted from the Intermediate system to obtain the Basic system. Elements are added to the Intermediate system to obtain the Upgrade system. Corresponding changes to the software accompany the hardware element additions and/or deletions.

Adding a new function to PCAAS must include the following considerations:

- The data required for the new function must be formatted and introduced onto the IEEE 488 bus for the processor(s) involved in the new function.
- The processor implementing the new function's algorithms must "listen" on the bus for the data required for the function.
- The "menu" of mode selections for the new function must be added to the IDCC software such that the mode selections are offered to the pilot on the IDCC display.

An example of adding a new function, namely, FSS Data Link, is outlined below:

- A modem module must be added to the VHF transceiver to permit the reception and transmission of digital data.

- The output of the transceiver modem is arranged to comply with the RS-232C interface.

- A spare RS-232C I/O channel on the I/O module of the Flight Sensor Microcomputer is utilized.

- The data received by the Flight Sensor processor is formatted and issued on the IEEE 488 bus.

- The IDCC microcomputer listens for the digital data on the 488 bus and displays the message on the IDCC display.

System Interfaces

Electrical power.-PCAAS is powered with either 12V dc or 24 dc with a power option strap required to select between these options. Each element has its own regulated power supply to provide those power supply voltages required for the operation of that element. A variation of ±20 percent in the primary power is permitted. However, the power to the PCAAS power buses will be maintained within less than 1 percent.

Volatile memory protection.-The MCC uses volatile memory for the data memory storage buffers. Consequently, protection is provided in the PCAAS power supply to protect against power transients causing a loss of data being used in the processor computations. This power transient protection is provided in the form of batteries located in the MCC to protect against power transients which may last for up to a second.

Prior to power shutdown the data memory is off loaded on to the tape cartridge so that the volatile mission data may be recalled upon start-up. This feature permits several stops during a long flight plan without having to load all new data in prior to the flight. A battery in the microcomputer supply voltage lines provides for long power transients in flight. Logic is included to prevent accidental shutdowns from power transients during flight.

Serial digital interface.-The RS-232 is the standard serial digital interface used by PCAAS. The intermediate system includes four channels of RS-232 I/O. Two of the channels are used for the interface between the data cartridge mass memory and the NMD processor and the IDCC processor. The other two channels are spares.

Parallel digital interface.-The IEEE 488 bus is the standard parallel digital interface used by PCAAS. The Intermediate system utilizes seven 488 channels, one for each processor. In addition, there are five spare 16 bit channels which can be used for either IEEE 488 bus or for general parallel I/O.

The design of the IEEE 488 bus gives careful attention to preventing a component failure from causing a loss of the entire 488 bus, no redundancy is required or provided.

Cost Considerations

The summary of costs for three design points in the spectrum of PCAAS avionics is presented in Table 13. The costs used in Table 13 were based upon the list prices in 1977 dollars using the April 1977 issue of Business and Commercial Aviation magazine as a reference. A number of the sensor prices were taken from current catalogs on commercial transducers.

The cost of the Microcomputer Control Complex (MCC) was based upon off-the-shelf modules used to implement the MCC CPU, memory, and I/O. The costs used were list prices for quantity of one in 1977 dollars.

It is common practice in the general aviation avionics business for fixed-base operator to install avionics at the list price unless some unusual installation expense accrues. Consequently, no installation costs were included.

The cost of the MCC does not include non-recurring costs nor does it include any separable cost for software. However, the trend in cost reduction for microprocessor components is significant. The downward cost trend has been significantly greater than the inflation rate because of two factors: (1) the technology "turnover" is great which contributes to cost reduction (e.g., the bit density on RAM chips is quadrupling in about two years), (2) the application of microprocessor technology to a variety of commercial products is accelerating at an exponential rate.

TABLE 13. PCAAS PHYSICAL CHARACTERISTICS AND COSTS

SYSTEM ELEMENT	BASIC SYSTEM QTY	WT	PWR	COST	INTERMEDIATE SYSTEM QTY	WT	PWR	COST	UPGRADE SYSTEM QTY	WT	PWR	COST
NAV RADIO #1	2[1]	19.6	24.0	2,000	1	3.7	11.2	1,400				
NAV RADIO #2[2]					1	3.3	12.0	1,700	2	6.6	24.0	3,400
DME					1	9.3	24.0	4,200	2	18.6	48.0	8,400
ADF					1	6.8	5.5	1,500	2	13.6	11.0	3,000
OMEGA NEW PCAAS					1	17.2	24.5	6,000	1	20.0	28.0	6,000
COMM RADIO					2	6.6	67.8	2,000	2	6.6	67.8	2,000
TRANSPONDER	1	3.0	14.0	600	1	3.0	14.0	600	2	6.0	28.0	1,200
WEATHER RADAR					1	20.0	68.8	5,500	1	14.9	98.0	7,100
RADAR ALTIMETER					1	2.5	8.4	1,000	1	4.5	15.1	2.300
ELT	1	3.0	-0-	125	1	3.0	-0-	125	1	3.0	-0-	125
ALTITUDE DIGITIZER	1	1.8	4.2	550	1	1.8	4.2	550	1	1.8	4.2	550
TAS SENSOR	1	0.6	0.1	90	1	0.6	0.1	90	1	0.6	0.1	90
PRESS ALT SENSOR	1	0.6	0.1	80	1	0.6	0.1	80	1	0.6	0.1	80
OAT SENSOR	1	0.3	0.1	30	1	0.3	0.1	30	1	0.3	0.1	30
MP SENSOR					2	1.6	0.2	170	2	1.6	0.2	170
FUEL FLOW RATE SENSOR	1	0.8	-0-	125	2	1.6	-0-	250	2	1.6	-0-	250
EGT SENSORS	1	0.1	0.1	125	8	1.0	0.1	1,000	8	1.0	0.1	1,000
DIR GYRO	1	4.0	15.0	2,300	1	5.4	20.0	3,000	2	10.8	40.0	6,000
ADI	1[3]	2.0	-0-	1,200	1	5.4	10.0	2,600	2	10.8	20.0	5,200
YAW RATE GYRO					1	1.8	2.0	300	1	1.9	2.0	300
MCC NEW PCAAS	1	8.3	40	2,900	1	20.8	100	8,775	1	20.8	110	9,700
STATUS DISCRETES NEW PCAAS					5	1.0	0.5	300	10	2.0	1.0	600
TAPE CARTRIDGE NEW PCAAS					1	3.0	49.5	300	1	3.0	49.5	300
IDCC NEW PCAAS	1	9.1	17.5	2,000	1	9.1	17.5	2,000	1	9.1	17.5	2,000
NAV MAP DISPLAY NEW PCAAS					1	9.0	16.0	2,000	1	9.0	16.0	2,000
AFCS ACTUATORS	1	9.0	25	750	2	18.0	50.0	1,500	3	12.0	75.0	2,250
MISC	1 lot	8.0	4.0	400	1 lot	20.0	10.0	1,000	1 lot	40.0	20.0	2,000
PCAAS TOTAL		70.2#	144.1W	$13,275		176#	516W	49,570		220.6#	890W	$66,045
NEW PCAAS TOTAL		17.4#	57.5W	$4,900		49.7#	208W	$17,900		63.9#	222W	$20,600

1. NAV/COMM FUNCTION
2. INCLUDES GS RCVR
3. VERTICAL GYRO

It is believed that the downward cost trend coupled with large quantity production of PCAAS type systems make the MCC cost numbers a sound projection of the expected selling price.

Furthermore, the microprocessor type selected for PCAAS represents the central tendency of the application. Also the use of the new Am 9511 arithmetric processor chip has permitted the MCC to avoid the use of 16 bit microprocessors for the more sophisticated computations. The downward cost trends for 16 bit technology is not yet as great as for 8 bit technology because of the lower volume of applications.

It may be noted from Table 13 that the "new PCAAS" elements are a small fraction of the total PCAAS cost since considerable off-the-shelf elements are used. The percentage of new PCAAS element cost to the total cost for the three design point systems are as follows:

- Basic system $ 4,900/13,275 = 37%
- Intermediate system 17,900/49,570 = 36%
- Upgrade system 19,600/66,045 = 30%

Certain elements used in PCAAS will require modification to be used in the PCAAS interface as defined. In general these modifications involve deleting unnecessary hardware for the PCAAS digital interfaces. For example, the navigation and communication radios require hardware to provide manual tuning and mechanical digital frequency displays which are unnecessary when digital commands are issued to the radios' frequency synthesizers.

At present the avionic manufacturers have built "fences" around their avionic suites by establishing peculiar "company interfaces." This strategy helps win a complete suite for new aircraft, but does not work well in upgrading the avionics in existing aircraft. The upgrade of avionics in existing aircraft represents a larger potential market than new aircraft.

The evolution of a standard digital interface appears probable for the following reasons:

- A standard interface will permit avionic manufacturers to "cross company lines" in the large retrofit market for general aviation aircraft.

- The cost of unnecessary hardware can be eliminated if a standard evolves which will be beneficial to user and manufacturer alike.

- Cost reduction allowed by the standard interface will offset some of the new PCAAS element costs.

IDCC MODE DESCRIPTIONS

The functional capability of the PCAAS is available to the pilot through the Integrated Data Control Center (IDCC). As currently envisioned, the pilot selectable modes in the IDCC shall be as follows:

- Flight management
- Engine management
- Navigation
- Map modes
- Checklists

Each of these modes are described in the following paragraphs.

Flight Management

The PCAAS flight management function represents a significant increase in capability over current avionic systems which are primarily area navigation systems with minor embellishments such as checklists, etc. A summary of the features of the flight management system is given below.

- Aircraft performance:
  1. Displays takeoff and landing performance as a function of aircraft weight, altitude, and temperature.
  2. Computes and displays maximum performance speeds such as V_x, V_y, V_{yse}, V_{max} L/D. In the case of a twin V_{yse} will be displayed automatically if the engine health system senses a failure.
- Fuel management:
  1. Computes fuel used and remaining.
  2. Continuous update of fuel reserves at destination or selected alternates based on current winds as computed by the navigation system.
- En route calculations:
  1. Computes climb or descent rate required to cross a specified fix at a specified altitude.
  2. Computes range at current or selected power settings.

3. Computes altitude and power settings for maximum range or endurance.

- Weight and balance calculations:
   1. Pilot inputs weights and PCAAS computes point in loading envelope.
   2. Upgrade version automatically computes weight and balance based on strain gauges on gear and pitch attitude on ground.
   3. Provides continuous update of weight and balance as fuel burns off. This data is primarily utilized by the aircraft performance subsystem.

Engine Management

The engine management function provides the pilot with timely information relative to his power plant which is usually available or must be derived from engine handbook curves and tables.

It is felt that this mode will play a significant role in reducing pilot workload. Conceptually the desired workload reduction is to be accomplished by providing the single pilot with information usually looked up or computed by the co-pilot. The key elements of the engine management function are the mixture control flight director and a command bug on the manifold pressure indicator. A block diagram illustrating the conceptual mechanization of such a system is shown in Fig. 20. Utilization of this system would proceed as follows. The pilot first selects the desired horsepower. This would be obtained from the flight management mode based on pilot selected options consisting of desired true airspeed, miles per gallon, gallons per hour, maximum endurance or maximum range. Secondly, the pilot sets the engine rpm(s) based on noise and vibration characteristics of his particular engine airframe combination. The manifold pressure command bug automatically slews to the proper value to obtain the pilot commanded horsepower at the current value of altitude and outside air temperature. Likewise, the mixture control flight director commands the proper control setting to obtain the appropriate fuel air ratio for the horsepower being developed. In the example mechanization shown in Fig. 20, the fuel-air ratio is adjusted via fuel flow. The accuracy of current fuel flow sensors is well within

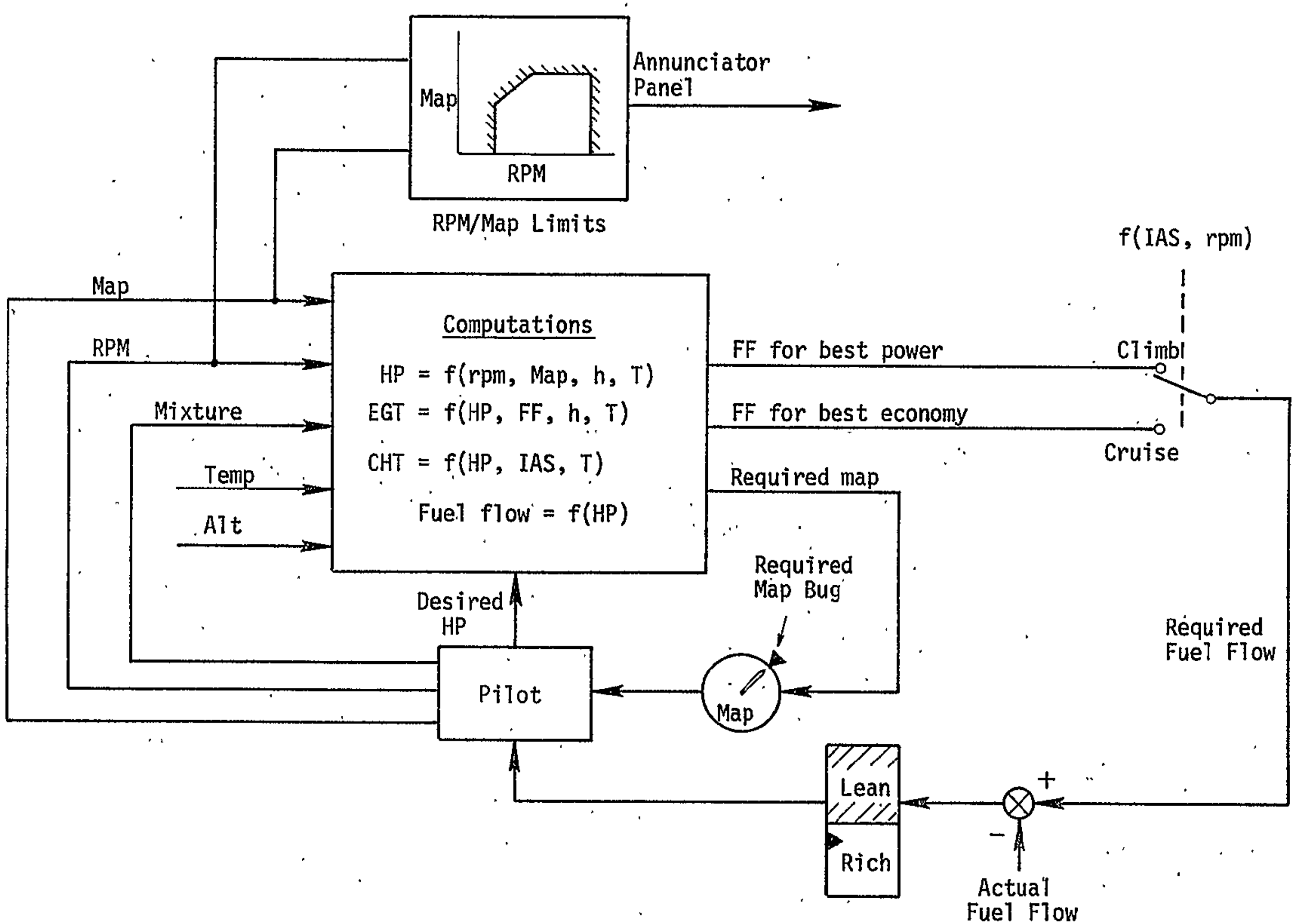


Figure 20. Engine Management Via Fuel Flow

the required range (better than 1 percent) and cost goals of the PCAAS system (about $250). An alternate scheme for leaning is to measure fuel-air ratio at each cylinder and to lean so as to maintain the proper fuel cooling in the leanest cylinders. A mechanization for accomplishing this via EGT is shown in Fig. 21. The drawback to this technique is that the stochiometric fuel-air ratio occurs at peak EGT. Hence, accurate mixture settings require leaning to peak which is a disadvantage, both from the standpoint of mechanizational complexity and operationally when the horsepower exceeds 75 percent (EGT should not be increased above 100° F to 150° F below peak because of critical fuel cooling requirements at 75 percent or more power). Possible solutions may be forthcoming from the automotive industry, which now has a requirement to measure fuel-air ratio to meet the new emission standards. Reference 5 discusses the development of Zirconium Dioxide sensors which allow direct sensing of fuel-air ratio. It would seem that a limited amount of experimentation to determine the most efficient leaning technique will necessarily be a part of the PCAAS development. It should be noted that, as with many other PCAAS developments, the results of such limited experiments would be of significant value to general aviation.

Engine Health

The engine health function is basically a management by exception mode in that messages are displayed to the pilot only when engine limitations are being exceeded. Engine parameters such as fuel-air ratio, fuel flow, manifold pressure, rpm, cylinder heads temperature, and oil temperature will be continuously monitored and checked against limit exceedences. Should any parameter approach its limiting value, an alert message shall be displayed to the pilot on the IDCC CRT display. This message shall override any information which is currently being displayed on the IDCC CRT and should flash on and off to attract immediate pilot attention. The pilot can return to the interrupted display by selecting "status override." In addition to displaying the problem, the system shall also indicate the proper pilot action. For example, if the manifold pressure rpm envelope is exceeded, the message would read "reduce throttle or

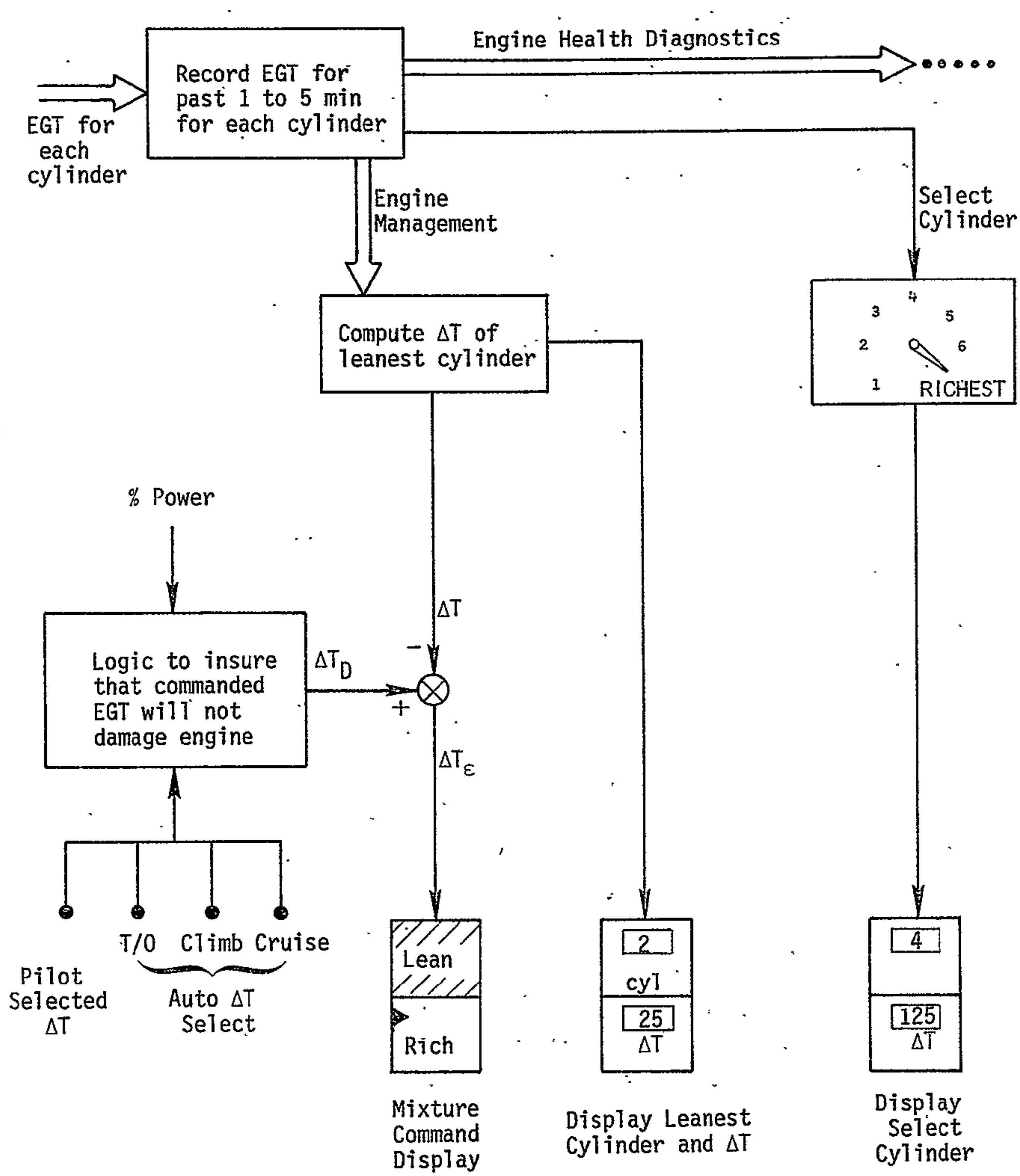


Figure 21. Engine Management via EGT

increase rpm." An example of the decision tree logic which would apply if exhaust gas temperature (EGT) is used to measure fuel-air ratio is given in Fig. 22.

It should be noted that some features of the engine health mode cannot be incorporated into PCAAS without at least a limited research program. This is required to relate quantitative trend data on engine parameters to certain failure modes.

In many cases it is desirable for the pilot to be able to request engine data even though all parameters are within limits. Therefore the following parameters will be available on request:

- Current fuel-air ratio at each cylinder and
- Max/min during past 15 min
- Max/min oil temperature excursions
- Max/min cylinder head temperature excursions
- Turbo inlet temperature excursions

Navigation

Most of the calculations to be performed in the navigation function are not new and are representative of current generation area navigation systems. However, the transformation of processed navigation data into a Navigation Map Display (NMD), at costs consistent with general aviation budgets, is felt to be a significant contribution towards reducing the pilot's workload. Integration of the NMD with the Integrated Data Control Center (IDCC) will allow the pilot to key en route structures based on VOR, airport, and airway labels as they appear on the map, as opposed to the laborious and error prone latitude and longitude entries required in current area navigation systems. If VHF up-link becomes available, the PCAAS will be capable of accepting and displaying clearances on the IDCC CRT surface as well as on the NMD.

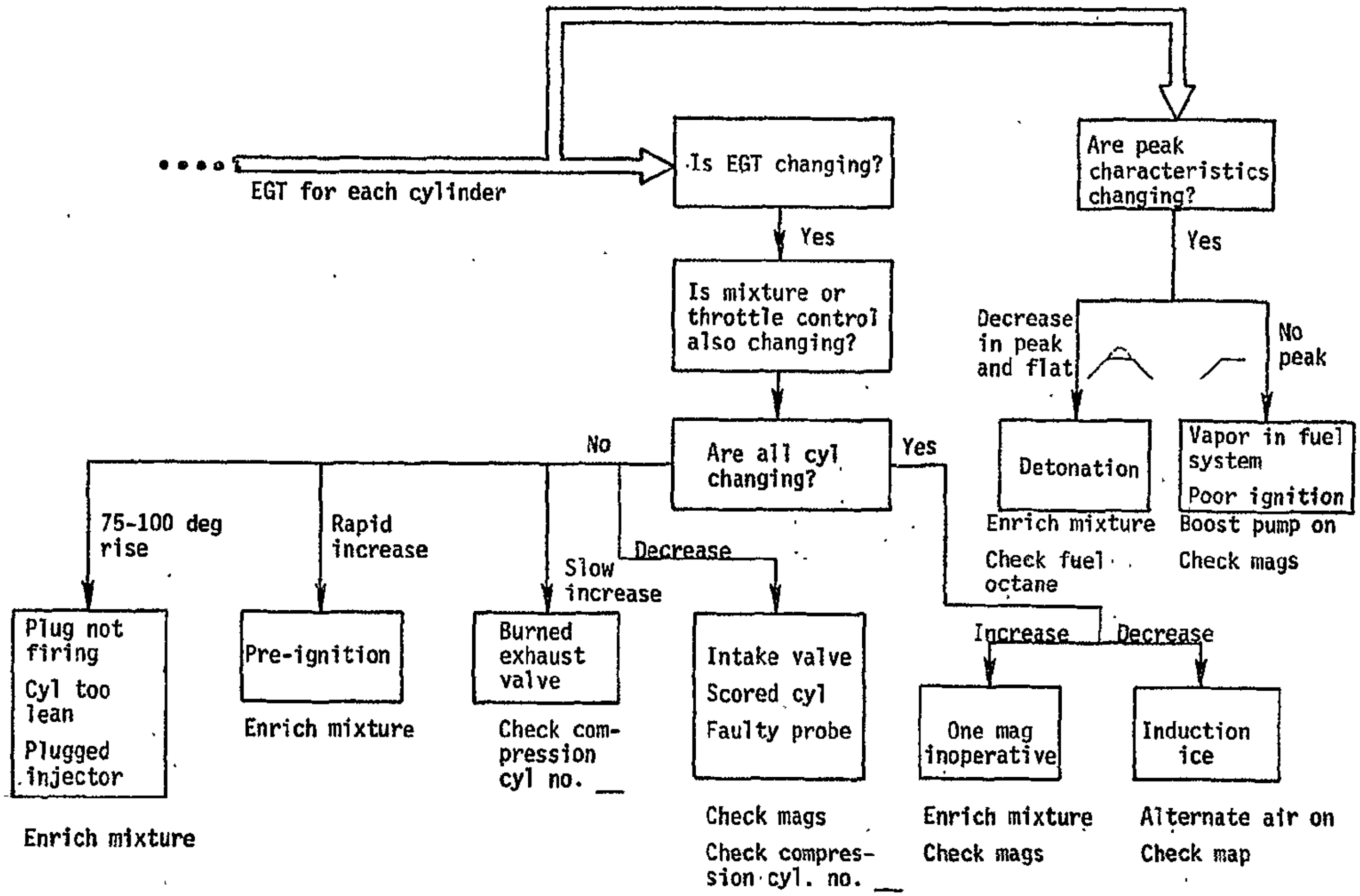


Figure 22. EGT Trend Diagnostics

Map Modes

This function gives the pilot control over the format of the moving map display. The following options shall be available

- Mode select:
  1. En route mode (Fig. 9)
  2. HSI mode (Fig. 10)
- Scale select — allows the pilot to select map scales in the en route mode.
- Area select — allows the pilot to look at different parts of his route.
- Map orientation — allows the pilot to select nearest octant up or north up.

The mode select and map orientation functions shall also be available on the map console. This is to allow the pilot to change modes or orientation without getting into the map mode function on the IDCC.

Checklists

The following checklists shall be displayed upon request:

- Prestart
- Takeoff
- Cruise
- Landing
- Shutdown
- Hot start
- Cold start

The following checklists shall be displayed automatically or selected by the pilot when desired:

- Engine failure
- Fire
- Propeller overspeed
- Door open

The planned modular buildup of the IDCC functions for the Basic, Intermediate, and Upgrade user is given in Table 14.

TABLE 14. MODULAR BUILDUP OF IDCC FUNCTIONS

IDCC FUNCTIONS	LEVEL OF MODULAR BUILDUP OF IDCC		
	BASIC	INTERMEDIATE	UPGRADE
A. Flight Management			
• Flight Planning			
1. Enter route data via VORS and airports or LAT-LONG	X	X	X
2. Display fuel required, ETE, reserves	X	X	X
• Fuel Management	X	X	X
• Speeds for best performance		X	X
• Optimum climb descent profiles			X
• Weight and Balance			X
• Takeoff and landing performance		X	X
• Cruise calculations		X	X
B. Engine Management			
• MAP and Mixture flight director			
1. Based on desired HP	X	X	X
2. Based on desired TAS, MPG, GPH		X	X
3. Based on max endurance on range		X	X
• Display standard power setting data (MAP & RPM for given HP and alt, etc.)	X	X	X
C. Engine Health			
• Display items leading to impending failure — flash on and off	X	X	X
• Display status on request		X	X
• Display past trends for analysis by engine shop			X

TABLE 14. (Concluded)

IDCC FUNCTIONS	LEVEL OF MODULAR BUILDUP OF IDCC		
	BASIC	INTERMEDIATE	UPGRADE
D. Navigation			
• Navigation Map Display		X	X
• Position display ρθ or ρρ from selected navaids or display LAT-LONG — Display GS & wind	X	X	X
• Auto tune — automatically tune best navaids to fix position on MMD		X	X
• Status — display what navaids are tuned and estimated errors		X	X
• Compute ETA			
1. Point selected on keyboard	X	X	X
2. Point selected from range cursor on MMD		X	X
E. Checklist			
• Routine checklists as requested from keyboard	X	X	X
• Automatically displayed emergency checklists	X	X	X
F. Flight Status Correlation			
• Navigation signals — compare VOR-VOR: VOR-DME: LOC-LOC, GS-OM		X	X
• Instrument crosschecks			X
G. Status Override (engine prob or emergency checklist)	X	X	X
H. Nearest Alternate		X	X
I. Select Map Modes		X	X

SYSTEM MAINTAINABILITY

Maintenance Philosophy

The PCAAS system is comprised of current off-the-shelf avionics elements and "new PCAAS" elements. The off-the-shelf elements in many cases have a digital interface with the new PCAAS elements. The maintenance approach differs from the off-the-shelf avionics elements and the new PCAAS elements. The maintenance approach for the current off-the-shelf (OTS) avionics is well established and will not be elaborated herein. The maintenance approach for OTS avionics is for the pilot to note a functional failure, report the failure to the avionics shop at the fixed-base operator (FBO), the avionics maintenance man removes the failed unit, tests it in the avionics shop, replaces modules until it works, reinstalls the unit in the aircraft, and checks it out.

The maintenance approach for the new PCAAS elements is similar to the OTS avionics; however, the ability to load diagnostic programs in the MCC to aid in isolating failed elements is an added feature. The diagnostic test routines can test both the new PCAAS elements, as well as the OTS elements which have a digital interface. For example, in case of a failure in the MCC itself the diagnostic tests are devised to permit isolation of the failure to a given MCC processor.

The failed unit is removed from the aircraft and taken to the avionics shop for repair. Normally the unit is repaired by isolating the failure to a module and replacing the module. The module is then returned to the factory for repair. In many cases, however, the avionics shop will repair the module by replacing a "flat pack" (IC) or other failed component which is isolated by probing during module troubleshooting. Module repair requires a higher level of skill than module replacement.

An advantage of returning modules to the factory for repair is that any upgrade changes in the module may be made at that time. The modular architecture of the PCAAS is an aid in fault isolation and repair.

Maintenance Actions

The maintenance actions for PCAAS include the method of fault identification or isolation, the avionics shop action, and the checkout required after repair. Table 15 summarizes the maintenance actions for the PCAAS Intermediate system elements. Table 15 also includes an estimate of the mean-time to repair each element in minutes. The MTTR is the time to repair the element after it is removed. The mean-time to remove and replace the item must be added to the MTTR to obtain the total repair time. The removal can, in general, be accomplished by a less skilled person than the repair.

TABLE 15. MAINTENANCE ACTIONS

PCAAS Element	Classif.	Method of Fault Isolation	Avionics Shop Action	Checkout After Repair	Estimated MTTR* (min)
NAV Radio #1	OTS	Pilot observes malfunction	Replace modules Adjust alignment	Read radial Test signal	30
NAV Radio #2	OTS	Pilot observes malfunction	Replace modules Adjust alignment	Read radial Test signal	30
DME	OTS	Pilot observes malfunction	Replace modules Adjust alignment	Emulate dist signal	20
ADF	OTS	Pilot observes malfunction	Replace modules Adjust alignment	RF test set	20
OMEGA NAV	New	Negative correlation with VOR/DME or pilot observes malfunction	Test program Isolate module	Check on ground Correlate in flight	20
COMM Radio	OTS	Pilot observes malfunction	Replace module Adjust alignment	Radio check with tower	30
Transponder	OTS	Ground controller reports no return. Pilot observes no illumination flash	Replace modules	Check for illumination from surveillance radio on ground	20
Weather Radar	OTS	Pilot observes malfunction	Replace modules Adjust alignment	Check in ground map for video pointing	50

*MTTR = Mean time to repair in minutes

TABLE 15 (Continued)

PCAAS Element	Classif.	Method of Fault Isolation	Avionics Shop Action	Checkout After Repair	Estimated MTTR (min)
Radar Altimeter	OTS	Pilot observes malfunction	Replace modules Adjust alignment	Check in flight	30
ELT	OTS	Periodic shop test	Test for radiation. Replace battery and/or modules	N/A	15
Altitude Digitizer	OTS	ATC reports no ALT Reply Pilot notes no digital ALT MCC notes no ALT.	Check with barometric source. Replace modules	Check for ALT reply	15
IAS Sensor	OTS	Pilot notes malfunction	Check IAS transducer and replace	MCC Verifies IAS	20
Press Alt.	OTS	Pilot notes malfunction MCC flags no signal	Check transducer and replace	MCC verifies signal	20
OAT Sensor	OTS	Pilot notes malfunction MCC flags no signal	Check transducer and replace	MCC verifies signal	20
Manifold Pressure	OTS	Pilot notes malfunction MCC flags no signal	Check transducer and replace	MCC verifies signal	20
Fuel Flow Rate	OTS	Pilot notes malfunction MCC flags no signal	Check transducer and replace	MCC verifies signal	20
EGT Sensor	OTS	Pilot notes malfunction MCC flags no signal	Check transducer and replace	MCC verifies signal	20

TABLE 15 (Concluded)

PCAAS Element	Classif.	Method of Fault Isolation	Avionics Shop Action	Checkout After Repair	Estimated MTTR (min)
Directional Gyro	OTS	Pilot notes malfunction MCC flags no signal	Check transducer and replace	MCC verifies signal	20
ADI	OTS	Pilot notes malfunction MCC flags no signal	Check transducer and replace	MCC verifies signal	20
Yaw Rate Gyro	OTS	MCC Fault isolation test	Check transducer and replace	MCC verifies signal	20
MCC	New	Diagnostic Program Isolates Processor	Diagnostic Program Isolates card. Replace card.	Diagnostic Program	55
Tape Cartridge	OTS	Pilot notes data base missing.	Replace cartridge drive	Diagnostic program	25
IDCC	New	Pilot observes malfunction Diagnostic program identifies faults	Replace modules	Diagnostic Program	75
NAV Map Display	New	Pilot observes malfunction Diagnostic program identifies faults	Replace modules	Diagnostic Program	75
AFCS Actuators	OTS	Pilot observes malfunction	Replace actuator	Ground check Flight check	75

SYSTEM RELIABILITY

System Serial Reliability

The failure rates for each element of the PCAAS Intermediate system are estimated in Table 5 and will not be repeated here. The failure rates are estimated by scaling the failure rates in relationship to the navigation radios which have a mean-time before failure (MTBF) of approximately 1000 hours or a failure rate of 1000 per one million (10^6) hours. The scaling is based upon an approximate complexity factor. It is believed that this method results in a reasonable estimate of the system MTBF.

The total system failure rate is the sum of the individual element failure rates or a total of 20,000 failures per million (10^6) hours. The serial MTBF of the system is the inverse of the failure rate or

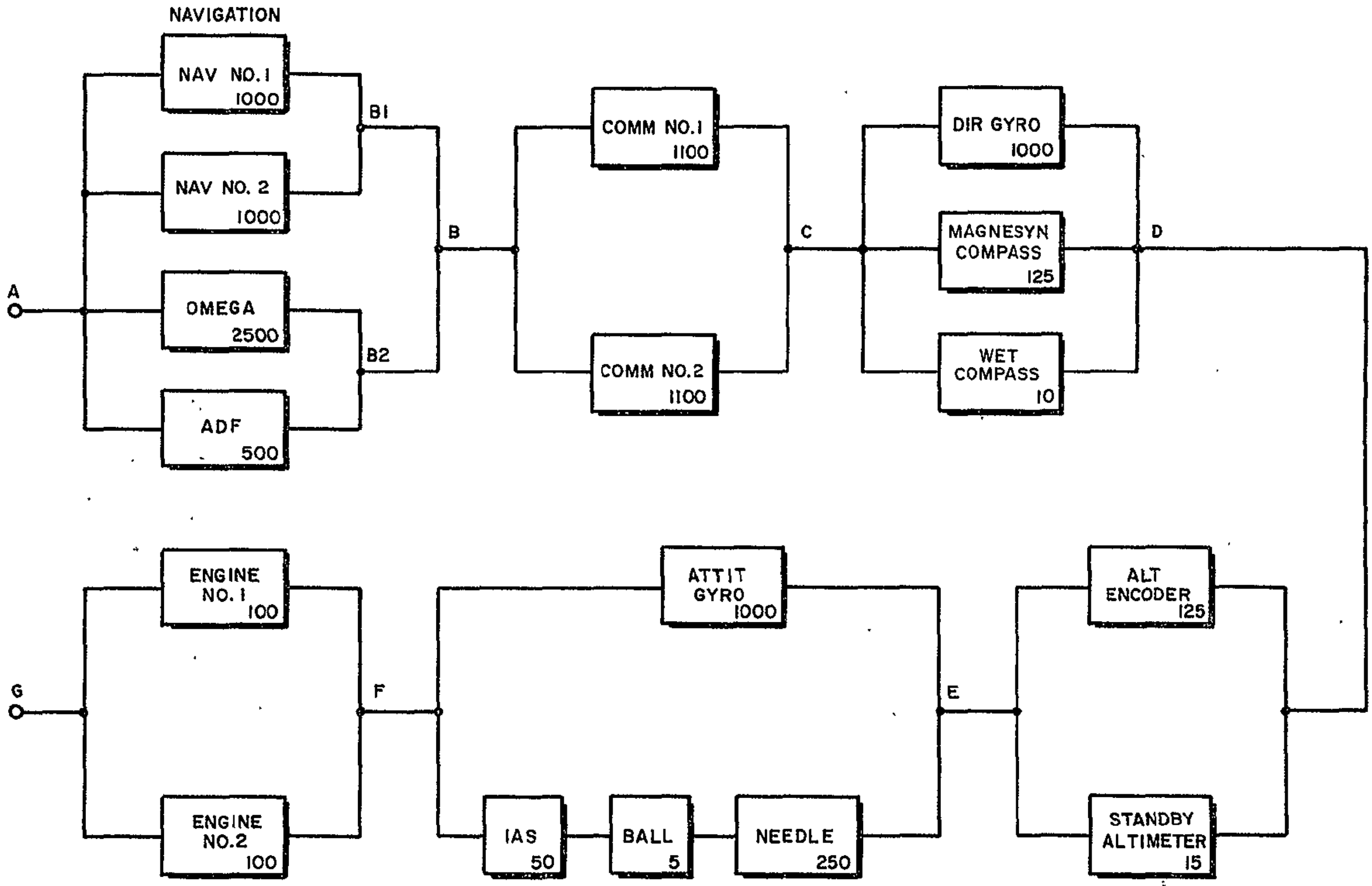
$$\text{MTBF} = \frac{1}{\text{Failure Rate}} = \frac{10^6}{20{,}000} = 50 \text{ hours} .$$

The serial failure rate is a measure of the frequency of maintenance actions required. A system MTBF of 50 hours means that on the average a failed element will have to be replaced or repaired once every 50 hours. This MTBF appears to be reasonable based upon experience with complex general aviation avionic systems.

System Mission Reliability

The PCAAS system architecture is devised to provide considerable functional redundancy. A simplified mission reliability computation is made for a four hour IFR flight. The mission reliability assumes that the failures are independent, which may not be strictly true. For example, if one engine fails, the probabily of the second engine failing is increased due to the greater stress placed upon the remaining engine.

The mission reliability diagram is shown in Fig. 23. The probability of mission success for a four hour mission is given by



NOTE: NO'S IN BOXES ARE FAILURES / 10^6 HRS

Figure 23. Mission Reliability Diagram

$$P_S = 1 - P_{\Sigma F} \qquad (1)$$

where

P_S = probability of success

$P_{\Sigma F}$ = summation of the probability of failure of all links in the mission reliability diagram

$$P_{\Sigma F} = P_{F_{AB}} + P_{F_{BC}} + P_{F_{CD}} + P_{F_{DE}} + P_{F_{EF}} + P_{F_{FG}}$$

The probability of two parallel elements failing is the square of the probability of one of the elements failing.

$$P_{F_{AB}} = (P^2_{F_{A1}})(P_{F_{A3}})(P_{F_{A4}}) = 0.000000$$

$$P_{F_{BC}} = 0.000019$$

$$P_{F_{CD}} = 0.000000$$

$$P_{F_{DE}} = 0.000000$$

$$P_{F_{EF}} = 0.000005$$

$$P_{F_{FG}} = 0$$

$$P_F = 0.000024$$

$$P_S = 0.999976$$

The probability of mission success for a four hour IFR mission exceeds "four 9's."

Electronic Component Reliability

The microprocessor manufacturers are beginning to issue reliability report data on microprocessor components. For example, in late 1975 INTEL issued reliability reports on the 1702A EPROM (RR-6), the 2107 4 K RAM (RR-7), and the 2102 1 K static MOS RAM (RR-9). The failure rate in failures per million hours for these components based on several score million device hours of testing was 0.020, 0.213, and 0.25 respectively.

The failure rates for a number of electronic component types are summarized in Table 16. These values were tabulated by one contractor for use in the Space Shuttle Interim Upper Stage (IUS) avionics reliability computations and are therefore reasonably current estimates.

The factor S_F is the inherent failure rate per million (10^6) hours. The factor π_Q is the weighting factor, or multiplier, to convert the inherent failure rate to predicted failure rate λ.

$$\lambda = S_F \pi_Q \tag{2}$$

TABLE 16. COMPONENT FAILURE RATE DATA

RESISTORS, FIXED				
CONSTRUCTION	STYLE	MIL-R-SPEC.	S_F	Π_Q
Composition	RCR	39008	.00045	.01
Film	RLR	39017	.0024	
Film	RNR	55182	.0028	
Wirewound	RBR	39005	.0085	
Wirewound	RWR	39007	.009	
Wirewound	RER	39009	.016	
RESISTORS, VARIABLE				
Wirewound	RTR	39015	.018	

CAPACITORS				
DIELECTRIC	STYLE	MIL-C-SPEC.	S_F	Π_Q
Paper/Plastic	CHR	39022	.0002	.01
"	CPV	14157		
"	CQR	19978		
Mica	CMR	39001	.0003	
Glass	CYR	23269	.0013	
Ceramic	CKR	39014	.01	
Tantalum, Solid	CSR	39003	.011	
Tantalum, Non-solid	CLR	39006	.015	

PART TYPE	S_F	Π_Q
Transistors		0.1
Si NPN	.028	
Si PNP	.042	
Ge PNP	.042	
Ge NPN	.12	
FET	.076	
Unijunction	.25	
Diodes		
Si, General Purpose	.017	0.1
Ge, " "	.022	
Zener & Avalanche	.027	
Thyristor	.023	
Si, Microwave Detector	.19	0.3
Ge, " "	.41	
Si, " Mixer	.25	0.1
Ge, " "	.72	
Varactor, Step Recovery, Tunnel	.24	0.3

	S_F
Connections	
Solder, Reflow Lap to P.C. Boards	.00012
Solder, Wave to P.C. Boards	.00044
Other Hand Solder Connections (e.g., wire to terminal board)	.0044
Crimp	.0073
Weld	.002
Wirewrap	.0000037

$\lambda = S_F \times \Pi_Q$ $\quad S_F$ = Failures/10^6 hr

PART TYPE	S_F	Π_Q
Inductive		1.0
Pulse Transformer	.0012	
Audio Transformer	.0025	
Power Transformers & Filters	.0075	
RF Transformers & Coils	.0096	
Connectors (per mating pair)		
Circular, Rack & Panel, Printed Wiring Board	.08	
Coaxial	.10	
Switches		
Toggle	.17	
Pushbutton	.11	
Sensitive	.27	
Rotary	.42	
Relays		
General Purpose	.13	
Contractor, High Current	.43	
Latching	.12	
Reed	.11	
Meter Movement & Bi-metal	2.4	
P.C. Wiring Boards		
Two-sided	.0015	
Multi-layer	.20	

INTEGRATED CIRCUITS		
CIRCUIT COMPLEXITY	S_F	Π_Q
Standard Bi-polar (TTL/DTL)		0.5
1-20 gates*	.0070	
21-50 gates	.020	
51-100 gates	.032	
101-500 gates	.14	
> 500 gates	2.2	
Memories, < 1000 bits	.12	
" 1001-4000 bits	.26	
" 4001-8000 bits	.44	
Bi-polar Beam Lead EGL, Bi-polar MOS Linear, Other MOS		0.5
1-20 gates	.010	
21-50 gates	.048	
51-100 gates	.076	
101-500 gates	.36	
> 500 gates	6.0	
Linear, ≤ 32 transistors	.012	
Linear, 33-100 transistors	.026	
Memories, ≤ 1000 bits	.32	
" 1001-4000 bits	.70	
" 4001-8000 bits	1.2	

*Gate is equivalent to 4 transistors.

MICROCOMPUTER COMPONENTS			S_F	Π_Q
INTEL	4K RAM	SiGn-MOS	0.213	0.5
NCR	4K EAROM	MNOS	2.19	
	1K EAROM	MNOS	2.10	
INTEL	2K PROM	SiGn-MOS	0.020	
	1K STATIC RAM	NMOS	0.25	
	4K PROM	Bi-Polar	0.79	
National	4K RAM	MOS	0.58	
	8080		0.8	

SYSTEM RISK ANALYSIS

The PCAAS risk areas can be divided into three general areas:

Category I:	Risk that national or international systems for which the PCAAS mechanization depends are not implemented as planned.
Category II:	Risk in the PCAAS mechanization techniques selected in the design to meet the PCAAS system specification.
Category III:	Risk in the availability of component technology on which the PCAAS implementation is based.

Category I Risks

Risks in Category I depend upon decisions by Federal and international authorities which are beyond the influence of PCAAS design effort. The modular design and functional redundancy of PCAAS reduces its vulnerability and delays or cancellations in the implementation of such national or international systems as:

- Microwave landing system
- Upgraded third generation ATC
- Loran C
- OMEGA
- NAVSTAR
- Digital data broadcast system

Table 17 summarizes the Category I risks.

Category II Risks

Risks in Category II can be minimized by careful consideration of the mechanization alternatives. A low risk backup mechanization is planned for each high or moderate risk system mechanization area for PCAAS. The Category II risks are summarized in Table 18.

TABLE 17. CATEGORY I RISK

RISK AREA	FACTORS CAUSING RISK	ALTERNATIVES TO REDUCE RISK
Microwave Landing System	Decision making on implementation in early stages. Slowness in implementation possible.	Continue to rely on VHF/UHF ILS.
Upgraded Third Generation ATC	DABS may not be available during evaluation phase of GA avionics. BCAS may not be available. IPC may not be available.	Use upgraded ATCRBS. Rely on ATC advisories. Rely on positive ATC.
Loran C (Upgrade only)	Near term implementation plan does not cover complete CONUS.	Utilize separate Loran C chains using TOA technique with Cesium Clock standard. Use OMEGA instead of Loran.
OMEGA	Implementation of full 8 stations beyond schedule. Installation continuity subject to political factors beyond U.S. control.	Utilize available stations. Continue to rely on VOR/DME.
NAVSTAR (Upgrade only)	System sponsored by DOD primarily for military applications. Subject to cancellation and delays.	Utilize low cost strap down inertial.
Digital Data Broadcast	Implementation subject to future FAA decisions. Ground capability may not be implemented.	Eliminate capability for digital data communications.

TABLE 18. CATEGORY II RISKS

RISK AREA	FACTORS CAUSING RISK	ALTERNATIVES TO REDUCE RISK
Flight Siduation Display	Use of commercial TV quality CRT. Potential high cost due to 10,000 ft Lambert viewing. Potential unacceptability of diagonal lines due to digital raster.	(1) Use mechanical "ball" type of attitude reference indicator plus LED type thermometer display for the radar altimeter, glide slope, and localizer indicator.
Navigation Map Display	Same as FSD plus. Generation of adequate symbology display.	(2) Use projected map display. (This alternative is probably unacceptable because of high cost.)
Microcomputer Control Complex	Plan to use 8 bit CPU to take advantage of low-cost microprocessor technology. No multiply or divide instruction may result in inadequate throughput. Long times required for sin/cos $\tan^{-1}$ algorithms.	(1) Use DDA techniques to reduce requirements for multipliers. (2) Use look-up tables for the transcendental functions.* (3) Use hardware multiply. (4) Use arithmetic processor unit chip (new).
Inertial Sensors	Plan to use conventional gyros, rate gyros, and accelerometers. High cost of conventional sensors represent threat to cost goals.	(1) Use low cost sensor techniques. (2) Use digital computations, low cost sensors to eliminate expensive inertial sensors. (The lack of maturity of this alternative introduces greater technical risk.)
Flight Management Fuel Management	Availability of suitable fuel quantity sensors.	(1) Integrate quantity used and subtract from initial quantity. (2) Calibrate fuel tank-sensor combination.
Weight and Balance	Availability of suitable weight sensors.	(1) Provide weight and balance computations based upon keyed in parameters rather than sensed parameters.
Engine Performance Computations and Optimum Power Settings	Lack of engine performance data from manufacturer in airframe environment.	Provision for collecting calibrated data to use in calibrations.
Kalman Filtering in Navigation Correlation	Number of states may induce large computer requirements.	Reduce number of states.
Weather Avoidance	Lightning detector system in early stages of development. Existing lightning detection system has serious operational flaws.	Use lost-cost weather radar.

*Sin, cos, e^x, log, etc.

Category III Risks

Risks in Category III were minimized by the selection of technology implied in the PCAAS final system specification. Consequently, Table 19 represents a list of attractive technologies which would be highly desirable to utilize in PCAAS, but which were rejected to reduce risk. These technologies should be tracked closely to determine if new developments, breakthroughs, or additional information should make use of these technologies in PCAAS at a sufficiently low risk to reconsider their use.

TABLE 19. ATTRACTIVE COMPONENT TECHNOLOGIES, CATEGORY III RISKS

ATTRACTIVE TECHNOLOGY	FACTORS CAUSING DEFERMENT	TECHNOLOGY SELECTED TO REDUCE RISK
High Resolution Liquid Crystal Display for Flat Surface Display	High resolution LDC's are in an embryonic state. HAC has demonstrated a 1" x 1" element.	Commercial TV quality CRT.
High Resolution 3 Color LED Matrix Display with Touch Switch Matrix for Flat Surface Display and Function/Mode Selection	Litton has built such a display for a military application, but it is high cost. Low-cost commercial version is in early conceptual stage of development.	Commercial TV quality CRT.
Low-Cost Pressure Sensors using Si Technology and Flux Gate Sensor for Attitude Sensing	Stanford has defined a concept and preliminary analysis of feasible system. Concept requires further maturation.	Conventional inertial sensor.
Magnetic Bubble Domain Memories for Off-Time Mass Memory	MBDM's are now available commerically but in small size and at high cost.	Magnetic tape.
Electrically Alterable (EAROM) Program Memory for MCC	EAROM's are commercially available, but are very slow write, and slow read. EAROM's are expensive.	Ultraviolet erasable PROM.

APPENDIX A

SUBSYSTEM TRADE STUDIES

The PCAAS system design was supported by tradeoffs that considered a wide variety of PCAAS architecture and subsystem candidate options. The emphasis in the tradeoffs was for the Intermediate system selection.

Microcomputer Complex Candidate Options

The primary MCC options are shown in Fig. A-1 and include options for the architecture, type of microprocessor, data memory, program memory, and mass memory. There were a number of attractive options in each category.

The architecture options considered for the PCAAS MCC included a range from a single high speed processor utilizing bit slice microprocessor technology to implement a 16 bit processor to the final selection (indicated by a heavy box) which consisted of seven distributed 8 bit microprocessors with arithmetic processor units to increase the throughput.

The advantage of using the 8 bit microprocessor is that this type of device is finding wide commercial application; consequently, the cost of the 8 bit microprocessor and its associated support chips (memory, I/O, etc.) is expected to have a dramatic decrease over the next decade. A major disadvantage of the 8 bit microprocessor — its lack of multiply and divide instructions — is overcome by using a parallel arithmetic processor unit chip (the Am 9511) which greatly increases the throughput of the 8 bit microprocessor for sophisticated computations such as those used in navigation and flight control. This new chip was announced in the spring of 1977 and will be available in sample quantities in September 1977.

The microprocessors considered varied from 4 bit single chip microcomputers to bit slice microprocessors with microcoding.

The data memory options considered included P channel MOS (PMOS), N channel MOS (NMOS), both static and dynamic, complementary MOS (CMOS), metalized-silicon nitride-silicon oxide semi-conductor (MNOS), and charge

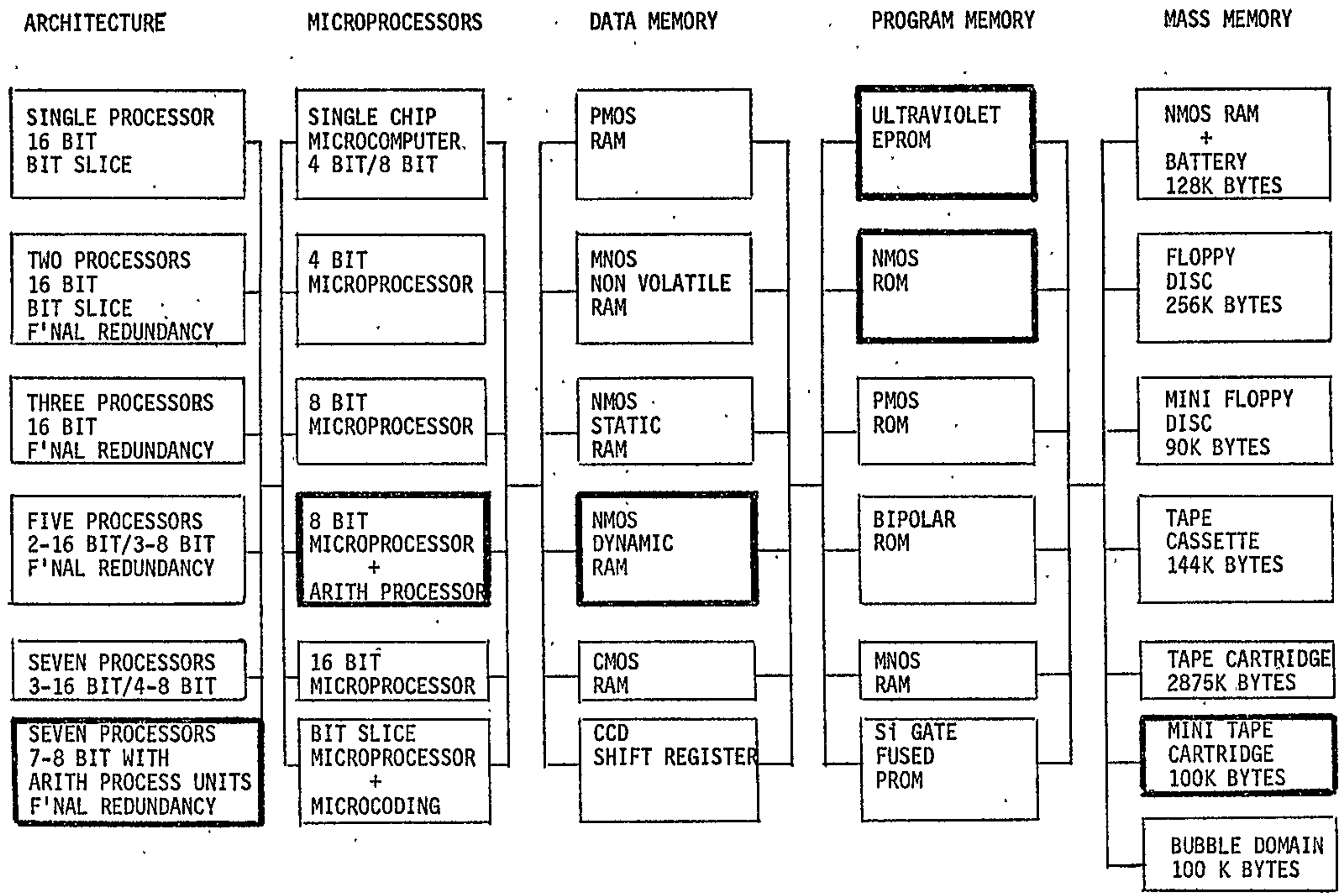


Figure A-1. PCAAS Candidate Options = Microcomputer Complex coupled devices (CCD) shift registers. The NMOS dynamic RAM (random access memory) was selected, because this is the area where dramatic increases in bit density and reduction in cost per bit are taking place. The CMOS has the advantage of minimum power, but is slower than NMOS. The MNOS is nonvolatile memory but is slow read and extremely slow write. There are specific areas of the MCC where a small amount of MNOS memory may be used, for example, for storing calibration coefficients which may change slowly.

The program memory selected utilizes ultraviolet Erasable Programmable Read Only Memory (EPROM), plus NMOS ROM. The EPROM is used during development when program changes are a frequent occurrence. The masked NMOS ROM is used when the program is not expected to change.

The mass memory selected was the digital mini-tape cartridge which has 100 bytes of storage capacity. The bubble domain memory is an attractive alternate, but it is not yet low cost.

Navigation and Communication Candidate Options

The navigation and communication options and selections are shown in Fig. A-2. The overall navigation system approach selected is that of dead reckoning (DR) using magnetic heading and indicated airspeed as inputs to the computation with the necessary connections being made to these parameters. The DR position is updated with dual VOR/single DME RNAV and/or OMEGA position on a periodic basis.

The other specific selections for the communication and navigation radios are indicated by the heavy boxes. In general the element with the lowest cost was selected.

The OMEGA selection is a new low-cost OMEGA which is targeted at a price of $6,000. The price objective for the low-cost OMEGA being supported by NASA Langley is $5,000.

The King KN-61 DME was considered, but the selection of the upgraded King KDM-705A was made because the lower cost King DME (KIV-61) is reported to be not as reliable.

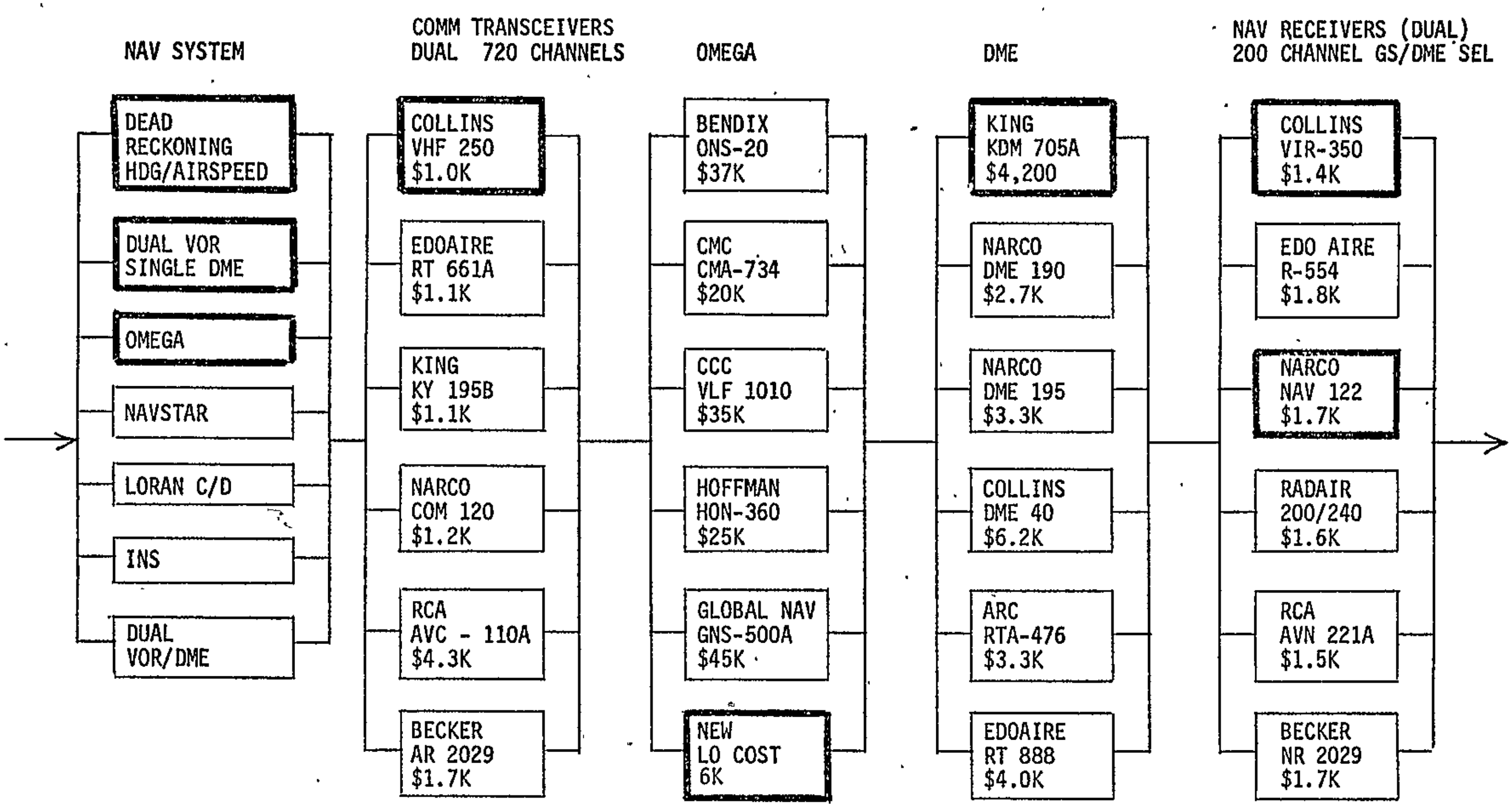


FIGURE A-2 PCAAS CANDIDATE OPTIONS = NAVIGATION AND COMMUNICATION

The Collins VIR-350 was selected for NAV Radio No. 1 and the NARCO NAV 122 was selected for NAV Radio No. 2 to provide an integrated glide slope receiver as well as VOR and localizer.

ATC Surveillance Candidate Options

The ATC surveillance elements include the 4096 transponder with modes A and C, the altitude digitizer for operating Mode C, weather avoidance sensor, and the radar altimeter. The options and PCAAS selections are illustrated in Fig. A-3.

The ATC transponders are very competitive with all costing less than $750. The lowest cost unit, the King KT78A, was rejected because it uses vacuum tubes. The NARCO 150 which is all solid state was selected.

The attitude digitizers are also competitively priced. The Aerosonic 1019 was selected as the lowest cost unit that meets the requirements.

The Bendix RDR 160 which has a digital raster scan display was selected for the weather avoidance sensor. The Ryan Stormscope was considered, but rejected because of a number of operational deficiencies relative to the weather radar. The King KWX 40 is the lowest cost weather radar. This unit was rejected because it uses a direct view storage tube rather than a short persistence TV scan display. The TV type display, such as used on the RDR 160, is more versatile in interfacing with the MCC as an optimal alternate display surface for alphanumeric or navigation map messages.

The Bonzer Mini Mark was selected for the radar altimeter because of its lowest cost. This unit is limited to a range of 40 to 1000 ft. The Hoffman HRA-100 and Sperry AA-100 represent low cost alternatives which have a maximum range of 2500 ft.

Flight/Engine Management and Displays Candidate Options

The sensors and displays candidate options are shown in Fig. A-4. The sensors selected are those which have a digital interface with the PCAAS MCC. Some of the sensors not selected are still provided for instrument displays which are not interfaced with the MCC. For example, fuel quantity

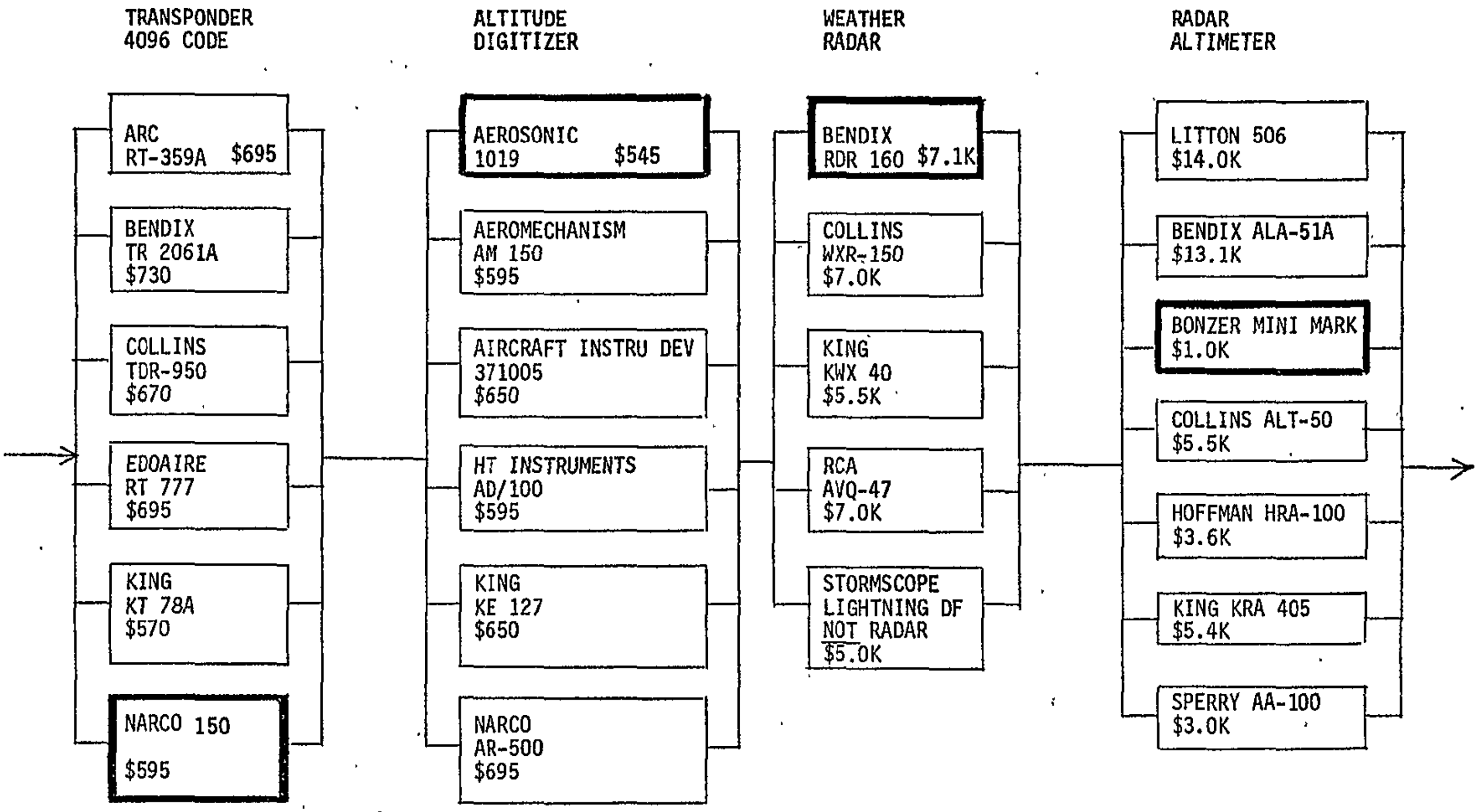


FIGURE A-3 PCAAS CANDIDATE OPTIONS - ATC SURVEILLANCE

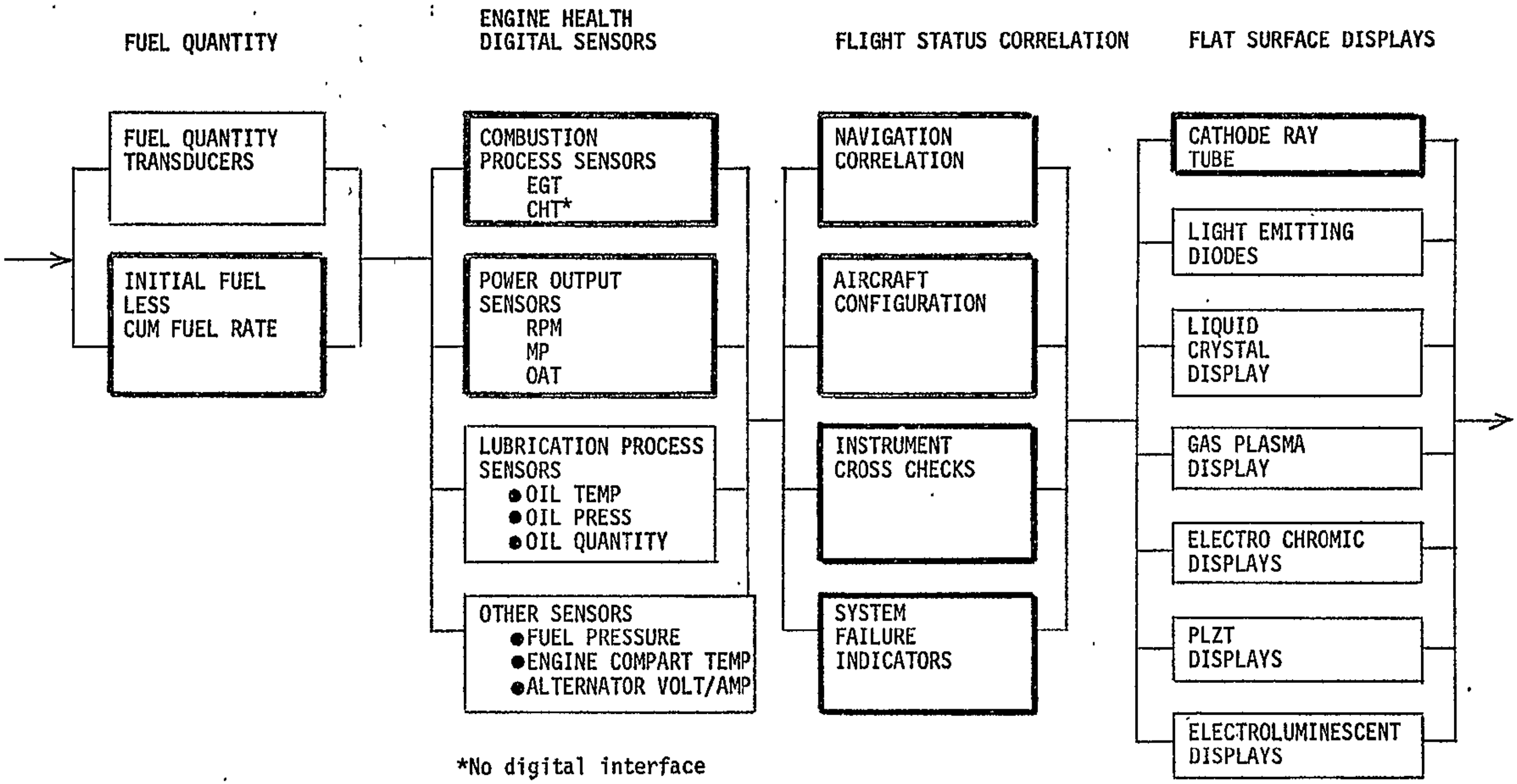


FIGURE A-4 PCAAS CANDIDATE OPTIONS - FLIGHT/ENGINE MGMT, DISPLAYS gauges, oil temperature and oil pressure gauges are provided, but not interfaced with the MCC.

The sensors selected with digital interface include the fuel rate sensor, EGT, RPM, MP, OAT, and IAS.

The cathode ray tube (CRT) was selected for the flat surface displays. However, several other alternatives are attractive candidates to replace the CRT when these technologies reach a higher level of maturity, including the LED, LCD, and electroluminescent displays.

Automatic Flight Control Candidate Options

The AFCS candidate options are shown in Fig. A-5. The decision was made to provide both lateral and longitudinal (pitch) modes for the PCAAS Intermediate system AFCS. The modes selected are those which give significant pilot work load reduction.

Electrical actuators were selected for the elevator and aileron. The electrical actuators are low cost, well developed and have acceptable dynamic characteristics for GA aircraft flight control.

Conventional inertial sensors were chosen to provide the attitude and rate signals used by PCAAS.

Off-the-shelf analog autopilots were considered for PCAAS; however, a digital autopilot was selected to be compatible with the PCAAS digital mechanization.

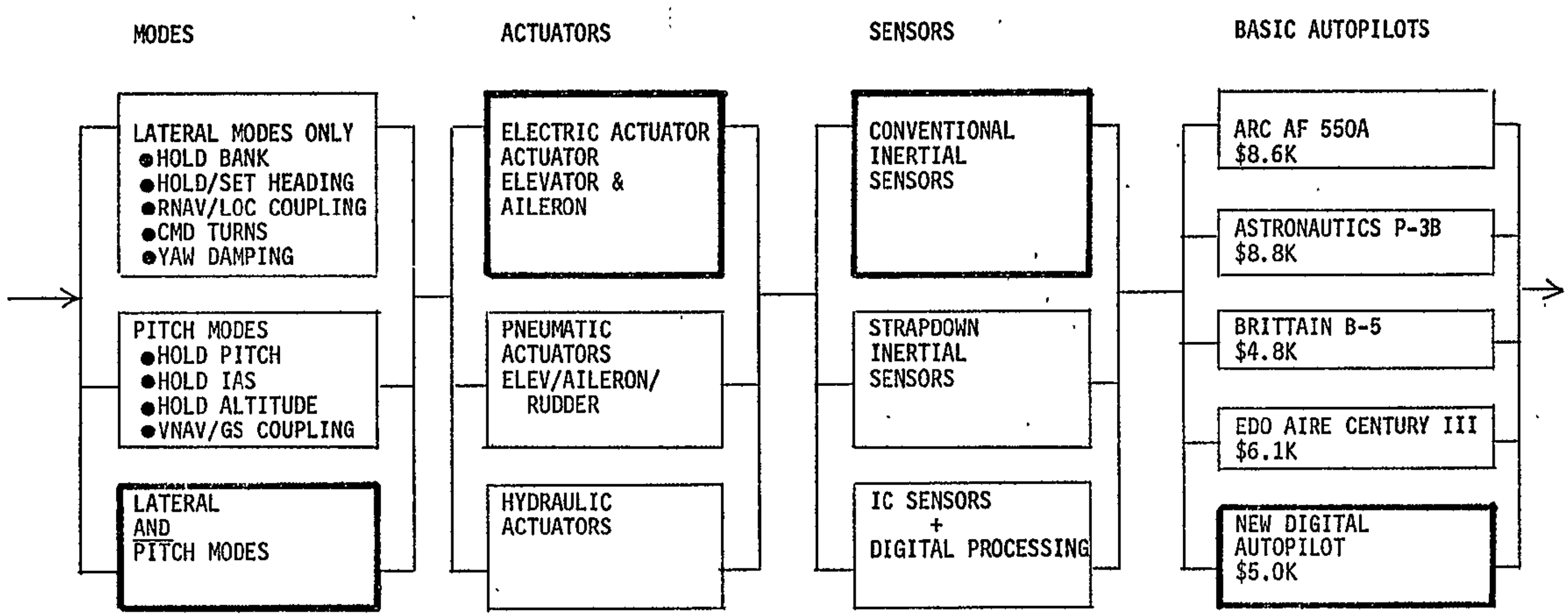


FIGURE A-5 PCAAS CANDIDATE OPTIONS - AUTOMATIC FLIGHT CONTROL

APPENDIX B

SYSTEM SPECIFICATION FOR PRELIMINARY CANDIDATE ADVANCED AVIONICS SYSTEM (PCAAS)

TABLE OF CONTENTS FOR APPENDIX B

SYSTEM SPECIFICATION FOR PRELIMINARY CANDIDATE ADVANCED AVIONICS SYSTEM (PCAAS)

1.0 SCOPE

This specification covers the design requirements for an advanced avionics system for general aviation aircraft in the 1980 to 1990 time period. The impetus for an advanced system is the increased demands expected of the National Air Traffic Control System in the 1980s. Single pilot IFR operations in higher density traffic environments without degradation in safety will require enhanced avionics system functional capability to reduce pilot workload. For an advanced system to be practical, it must also be affordable, reliable, and maintainable. The design objectives are increased system capability at current (or improved) levels of cost, reliability, and maintainability.

This specification is for the Intermediate category of general aviation aircraft represented by well equipped single engine aircraft and light twins, such as the Cessna Skyline, Rockwell 114, Beech Bonanza, Piper Seneca, and the Cessna 320, and 402.

In addition to this Intermediate Specification, two other systems denoted by "Basic" and "Upgrade" represent changes to this Intermediate Specification for two other points in the spectrum of general aviation aircraft. The three categories of aircraft are summarized in Table 1.0-1.

A summary of current avionics systems and prices for the Basic, Intermediate, and Upgrade aircraft categories in Table 1.0-1 is given in Table 1.0-2. The dollar amounts shown in Table 1.0-2 are based on avionics available on the market in 1976. The Basic category in Table 1.0-2 is aimed at the serious cross country pilot who needs IFR capability at minimum cost. Pilots with less stringent mission requirements are not considered as potential candidates for the PCAAS. The Intermediate category includes pilots that generally travel with a definite schedule commitment and will generally "go" unless the weather is severe (icing

TABLE 1.0-1. CATEGORIES OF GENERAL AVIATION AIRCRAFT

GA AIRCRAFT CATEGORY	TYPICAL EXAMPLES	AIRCRAFT MISSION	PCAAS AVIONIC FUNCTIONS REQUIRED
BASIC Fixed gear single engine aircraft, \$15-40K cost (covered by Basic Amendment to Intermediate Spec)	Cessna 172 American Traveller Piper Cherokee Beech Sundowner	(VFR and Light IFR) Pleasure; VFR, IFR Business, IFR Training	Communications Navigation and identification Lateral axis flight control Flight management
INTERMEDIATE Well-equipped single engine and light twin \$40-200K cost (covered by Intermediate Spec)	Cessna Skylane, Centurion Beech Bonanza, Baron Piper Arrow, Seneca Rockwell 112, 114 Cessna 310, 402	(VFR, Moderate IFR) Pleasure Business, IFR Individual Air taxi	Communications Navigation and identification Three-axis flight control Flight management Engine management Weather avoidance
UPGRADE Heavy business twins and business jets \$200K-4M cost (covered by Upgrade Amendment to Intermediate Spec)	Beech Queenair/Kingair Cessna 402 Rockwell Commander 680 Cessna Citation MU-2 Lear Jet IAI Westwind	(Heavy IFR) Business Third level airline Charter Air freight	Communications Navigation, identification Weather avoidance Long-range navigation Three-axis flight control Flight management Engine management Additional sensors; software and redundancy

TABLE 1.0-2

CURRENT (1977) AVIONICS SYSTEMS SUMMARY

	BASIC		INTERMEDIATE		UPGRADE	
	EQUIPMENT	1977 PRICE	EQUIPMENT	1977 PRICE	EQUIPMENT	1977 PRICE
Communications	Dual 720 ch[a]	$ 2,000	Dual 720 ch	$ 2,000	Dual 720 ch	$ 2,000
Navigation						
VOR/LOC	Dual 200 ch[a]	Incl. above	Dual 200 ch	3,100	Dual 200 ch and RMI	3,400
Glide Slope			Single 40 ch	725	Dual 40 ch	Incl. above
ADF			Digital	1,500	Digital, Dual	3,000
RNAV			1 waypoint	2,295	16 waypoints	12,500
VNAV	—	—	—	—	—	
DME			Single	4,200	Dual	8,400
OMEGA	—	—	—	—	Single	23,500
Automatic Flight Control and Flight Attitude Instruments	VOR, LOC, RNAV, DG	2,800	VOR, LOC, RNAV, DG, GS + Flt. Director + HSI + yaw damper + slaved gyro	14,100	VOR, LOC, RNAV, DG, VNAV; yaw damper + Flt. Director + slaved gyro	42,600
Transponder	275 watts 4096 codes	600	275 watts 4096 codes	600	275 watts 4096 codes	600
Altitude Encoding Altimeter		550	Good to 20,000	550	Good to 35,000	650
Radar Altimeter	—	—	Single	1,000	Single	2,300
Audio Panel + Marker Beacon	—	275	—	520	—	875
ELT	—	130	—	250	—	250
Wx Radar	—	—	Digital display	7,100	—	7,100
Totals		$ 6,355		$43,340		$107,175

[a]COMM radio/NAV radio combined.

or thunderstorms). This avionics suite is equivalent to airline aircraft in terms of capability (save INS) at moderate cost and represents the largest volume and most competitive area of the avionics marketplace. The Upgrade category represents an enormous price jump generally reflecting higher quality components.

The price guideline for the Intermediate PCAAS system shall be $45,000 (1977 dollars) based on the program objective of holding the price at current levels.

The primary advances in system capability are expected to occur through the use of microprocessor technology to provide system functions which will reduce pilot workload as follows:

- Automation of flight management and planning to greatly simplify preflight and inflight decision making
- Automatic correlation of flight status data including normal system crosschecks as well as emergency procedures
- Display information required for intelligent engine management
- Automatic monitoring and display of engine health
- Improved navigation displays to allow continuous orientation with respect to the map without mental conversion of needles and numbers
- Improved pilot/system interface

The above items represent a significant step toward satisfying the objective of increased system capability.

Microprocessor technology and a total integrated systems design approach can be expected to alleviate some of the cost impact of increased system capability. Unfortunately, there are some basic equipments which dominate current system cost and which will not likely be affected by advanced microprocessor technology alone. Sensors, NAV/COM equipment, and surveillance equipment are currently the primary cost drivers; these equipments include the following items:

- Reception of navigation and communications signals (RF circuitry)
- Attitude gyros with electrical pickoff. Specifically the vertical gyro for attitude control and the directional gyro as a heading reference
- Rate gyros for stability augmentation
- Electrical pickoff of other flight parameters

Although unconventional implementations of the above functions may be considered, the corresponding risk shall also be considered in the design tradeoffs between system capability, cost, reliability, and maintainability.

2.0 APPLICABLE DOCUMENTS

This section covers those documents which impose or imply design requirements on the Preliminary Candidate Advanced Avionics System (PCAAS).

2.1 "Project Plan for General Aviation Advanced Avionics System Technology," Enclosures No. 1 and No. 2 to RFP 2-26001(HK) dated October 31, 1976.

2.2 "Workshop on General Aviation Advanced Avionics Systems," Stanford University, November 5-6, 1975, NASA Contract No. NAS2-9023.

2.3 "Forecast of the General Aviation Air Traffic Control Environment for the 1980's," dated June 1976, Aerospace Systems, Inc., NASA Contract No. NAS2-9067.

2.4 "Computer Technology Forecast Study for General Aviation," dated June 30, 1976, Honeywell, Inc., NASA Contract No. NAS2-8971.

3.0 REQUIREMENTS

The Preliminary Candidate Advanced Avionics System (PCAAS) is to be designed in accordance with the general requirements set forth in 2.0, "Applicable Documents." The PCAAS system is applicable to the avionics required for general aviation aircraft in the 1980's. The general system guidelines set forth in 2.1 are summarized here:

a. The system shall allow single pilot IFR operation in high density terminal control areas.

b. The system shall be capable of operating within the proposed upgraded third generation ATC system.

c. The training and proficiency requirements to use this system shall be less than or equal to those currently required by instrument-rated pilots.

d. The ability of the aircraft to keep a desired trip schedule shall exceed or equal that expected from a light twin-engine aircraft used today for business purposes. (This guideline includes consideration of ability to operate in weather, maintainability, etc.)

e. The system should be such that it costs no more than the cost of a system typically installed in a light twin engine aircraft used today for business travel. The intent is to achieve a significant reduction in workload while maintaining costs at current levels.

f. The system shall be designed for both single and twin engine aircraft. Guidelines "d" and "e" are not meant to indicate the effort is directed towards twin-engine aircraft. These guidelines are given only to indicate that the desired level of capability is somewhat greater than typically found on single engine-aircraft today.

g. Modularity should be built into the system so as to allow a user to either upgrade his system or to purchase a lesser system that can be upgraded at a later date with a minimum cost penalty.

h. The system reliability should be better or equal to current avionics reliability levels.

The avionics considered typical of a light twin-engine aircraft used for business travel today will serve as a baseline from which improvements in cost, reliability, safety, maintainability, usability, etc. can be measured.

Three current avionic system baselines are defined in Table 1.0-2.

The PCAAS system architecture shall represent a major departure from current system design and architecture in its total capacity to transfer data across subsystem boundaries. The design shall utilize current or early 1980 technology. A Microcomputer Control Complex (MCC) and Integrated Displays and Controls (IDC) shall provide for higher level systems functions which cross subsystem/functional boundaries.

3.1 System Modes and Functions

The PCAAS modes and functions are summarized in Table 3.1-1 for the three categories of aircraft defined in 1.0. The PCAAS requirements are directed towards the Intermediate category.

3.1.1 Communication functions.-The PCAAS shall provide adequate communications capability for IFR flight within the Continental United States (CONUS) during the traffic control environment of the 1980's and shall be compatible with the upgraded third generation ATC system (UG3RD) as described in the document of 2.4.

3.1.1.1 VHF voice communications: The PCAAS shall provide voice communications in the VHF band from 118.0 through 136.0 M Hz with channel spacing of 25 K Hz or less thereby providing a minimum of 720 channels of communication. The capability to provide communication range of at least 100 N mi shall be provided at the minimum en route attitude (MEA).

The voice communication capability shall employ dual redundancy in order to assure a high degree of mission reliability during a four hour mission. The redundancy shall be such that no single failure shall cause a loss of two-way communication.

Means shall be provided such that PCAAS digital computer (hereinafter referred to as the Microcomputer Control Complex, MCC) can command any desired frequency within the above noted VHF band. The voice transceivers shall be automatically tuned to the command frequency in less than 100 msec for Simplex voice communications.

A backup tuning means shall be provided which is independent of the MCC.

TABLE 3.1-1. PCAAS FUNCTIONS AND MODES

	LEVEL OF SUBSYSTEM DESIGN EFFORT REQUIRED			BASIC	INTERMEDIATE	UPGRADE
	MAJOR	MINOR	NONE			
COMMUNICATIONS						
VOICE, VHF			X	Dual 720 ch	Dual 720 ch	Dual 720 ch
Digital Data Link			X	Touchtone	DABS & T/T	DABS & T/T
Remote Digital Frequency Selector			X	X	X	X
SURVEILLANCE						
Radar Beacon			X	Upgraded ATCRBS	DABS	DABS
Altitude Encoder			X	To 20K ft	To 25K ft	To 35K ft
Intermittent Positive Control			X	Simple CMD	ATSD	ATSD
Collison Avoidance System			X	BCAS	BCAS	ACAS
Weather Detection			X		X	X
Ground Proximity			X		Radar Altimeter 0-500 ft	Radar Altimeter 0-1000 ft
Emergency Locator Transmitter			X	X	X	X
NAVIGATION AND POSITION FIXING						
RNAV		X		VOR/DME	Dual VOR, single DME, OMEGA	Dual VOR, dual DME, OMEGA/ LORANC, NAVSTAR
VNAV		X			X	X
VHF LOC/GS			X	X	X	X
MLS			X		LOC/GS	LOC/GS
Kalman Filtering (Navigation Correlation)	X				X	X
Command Update		X		X	X	X
ADF			X		X	X
Marker Beacon Receiver			X	X	X	X
AUTOMATIC FLIGHT CONTROL						
Lateral Control						
Heading Hold/Set				X	X	X
NAV Coupling					X	X
VHF LOC Coupling		X			X	X
Standard Turn Rate Command					X	X
CWS						X
Pitch Control						
Altitude Hold					X	X
Airspeed Hold					X	X
Attitude Hold		X			X	X
Automatic Trim					Pitch	Pitch, yaw
VNAV Coupling					X	X
VHF GS/MLS GS Coupling					X	X
CWS						X
Stability Augmentation		X		Based on individual reqts.	Based on individual reqts.	Based on individual reqts.
Throttle Control			X			X

TABLE 3.1-1 (Concluded)

	LEVEL OF SUBSYSTEM DESIGN EFFORT REQUIRED			BASIC	INTERMEDIATE	UPGRADE
	MAJOR	MINOR	NONE			
CONTROLS AND DISPLAYS						
Flight Situation Display	X				X	X
Navigation Map Display	X				X	X
Integrated Data Control Center	X			X	X	X
System Status Display	X				X	X
Synthesized Voice Annunciator		X				X
Hard Copy Printer			X			X
FLIGHT MANAGEMENT						
Aircraft Performance	X			X[a]	X	X
Fuel Management	X			X[a]	X	X
Weight and Balance	X			X[a]	X	X
Miscellaneous Calculations	X				X	X
ENGINE MANAGEMENT						
Engine Performance Calculations	X			X[a]	X	X
Mixture Control Command	X				X	X
Manifold Pressure Command	X				X	X
Optimum Power Settings	X				X	X
ENGINE HEALTH						
Engine Status Monitor	X				X	X
EGT/CHT/Diagnostics	X				X (EGT)	X
Oil Temp/Pressure Diagnostics	X					X
Fuel Pressure Diagnostics	X				X	X
Stored Data for Later Analysis	X				X	X
FLIGHT STATUS CORRELATION						
Navigation Signals	X				X	X
Aircraft Configuration	X				X	X
Instrument Crosschecks	X				X	X
Aircraft System Failures	X				X	X
Avionics System Failures	X				X	X

[a]Values are keyed in from keyboard rather than measured.

3.1.1.2 Digital data link communications:

3.1.1.2.1 VHF data link

a. Digital messages

PCAAS shall have the provision for adding capability for digital data link over any of the VHF voice communication channels at the rate of 9600 baud using the UART/MODEM interface of the MCC for both up-link and down-link messages. Means shall be provided to display up-link messages on an alphanumeric display. The ability to store and recall up-link messages up to 1920 characters shall be provided. The data link message shall employ ASCII Code with parity.

b. Digital data broadcast system (DDBS)

PCAAS shall have the provision for adding capability for receiving digital data broadcast from a VHF communications channel consisting of the following RNAV data:

- Predesignated waypoints for RVAV routes
- Waypoints for SID and STAR procedures
- Definition of NAV frequency (frequencies) associated with each designated waypoint.

The PCAAS shall have the provision for storing broadcast streams of data and processing this data for en route RNAV using preflight selected RNAV routes.

The RNAV waypoints shall be referenced to VORTAC stations, rather than latitude/longitude points. (Latitude/longitude of waypoints may be stored in the system data base.)

3.1.1.2.2 DABS data link

PCAAS shall have provision for adding capability for two-way digital data link using the DABS transmitter at a data rate of 256,000 baud. The up-link message shall consist of an 8 bit message code including parity which represents a command for data to be down-linked. The up-link commands include, for example:

- Aircraft magnetic heading
- Aircraft airspeed
- Aircraft altitude
- As well as requests for status data

The down-link message shall consist of 30 bit message including parity, data identifier, and parameter value.

3.1.2 Surveillance functions.-The PCAAS shall provide a number of surveillance functions to interface with the current ATC system and shall have provision for adding capability to operate within the UG3RD ATC environment. The surveillance system shall have the capability of observing potential flight hazards.

3.1.2.1 Radar beacon: The PCAAS shall have provision for adding capability for the Discrete Address Beacon System (DABS) capability required by the UG3RD ATC environment. The DABS transponder in the aircraft shall have an assigned address which is addressed by the ATC ground radar beacon interrogator. The address code length shall be 24 bits long which provides for 16.7 million discrete address assignments. The radar beacon shall operate in frequency band "D" (old "L" band) with 1030 M Hz assigned for transmit and 1090 M Hz assigned for receive (interrogation frequency).

The uplink message length shall be 32.5 μsec and the down-link message length shall be 120 μsec.

The DABS transponder shall be compatible with the encoding altimeter and shall be capable of down-linking encoded altitude over the altitude range of −1000 ft to 25,000 ft with an altitude quantization level of 100 ft.

3.1.2.2 ATC transponder: The PCAAS shall have a 4096 code ATC transponder with Modes A and C. An altitude encoder shall be provided with a range of −1000 ft to 20,000 ft approved for operation in Mode C of the transponder.

3.1.2.3 Intermittent positive control (IPC): The PCAAS shall have provision for adding capability for the IPC function in cooperation with the UG3RD ATC environment utilizing the Ground Air Traffic Control radar, ATC controllers, VHF data link, and DABS data link for high priority messages.

The IPC function shall receive relevant air traffic information from the ground stations over the VHF data link for up to five potential threat targets. The up-link message shall contain the following information:

- Latitude (5 characters) / Longitude (6 ch) of the ground ATC radar
- Range (3 ch) and Bearing (3 ch) of maximum of 5 potential threat targets
- Altitude (3 ch), Speed (3 ch), Heading (3 ch) of 5 potential threat targets
- Own Aircraft Range (3 ch) and Bearing (3 ch)

Note: The up-link message requires 80 msec at the specified baud rate of 9600.

The up-link message shall be repeated at intervals of not more than 10 sec. Note: This gives the capability of a single VHF channel servicing 125 aircraft simultaneously.

The MCC shall resolve the potential threat targets into X-Y coordinates with own aircraft at the center of the moving X-Y coordinates, to develop an Air Traffic Situation Display (ATSD).

Provision shall be made to display the ATSD on the Navigation Map Display (NMD) at pilot selection or automatically if a co-altitude conflict is predicted with 30 sec.

A co-altitude conflict is defined as another ATC target coming within 1 N mi within an altitude of ±500 ft of own aircraft.

In the case of a predicted conflict, the conflict aircraft shall be enclosed by a flashing box on the display.

In the event that the ground ATC controller or the ATC computer predicts a co-altitude conflict within 30 sec, PCAAS provision shall be made to accept an emergency message from the DABS transponder to provide emergency maneuver commands which may take the forms of

- Descend
- Climb
- Turn right
- Turn left
- Combination

An audio warning tone shall be issued for the emergency conflict.

3.1.2.4 Weather avoidance: The PCAAS shall provides means for weather cell avoidance utilizing a suitable sensor. The system shall detect weather activity using the sensor to determine range and azimuth angle to the weather activity. A pilot-controlled range azimuth sensor may be placed on the weather cell to read out the range and azimuth digitally when the cell is designated by a switch closure.

Provision shall be made to add the capability to superimpose the weather activity on the Navigation Map Display (NMD) on pilot designation of the weather cell.

3.1.2.5 Ground proximity warning subsystem (GPWS): The PCAAS shall provide means to detect ground proximity and issue appropriate warnings. A radar altimeter shall provide the basic sensor information for the GPWS. The MCC shall provide the data correlation to provide the required warnings. The System Status Display shall display the warnings. The following GPWS warnings are required to be issued:

- Excessive sink rate for altitude
- Excessive terrain closure rate

The warnings are issued in the form of a flashing red light and a modulated audio tone in the 400-800 Hz frequency band.

Also the capability of displaying terrain clearance below 1000 ft in digital form shall be provided.

3.1.2.6 Emergency locator transmitter (ELT): The PCAAS shall include an ELT which provides for activation of an emergency transmission when the longitudinal acceleration exceeds 5 g (+2, −0) for longer than 11 (+5, −0) msec. The ELT shall emit on the standard VHF/UHF emergency frequencies of 121.5/243.0 M Hz. The audio modulation shall be a downward sweeping audio tone of at least 700 Hz between 1600 and 300 Hz with a repetition rate of 2-4 times per second. The ELT is ancillary subsystem to PCAAS.

3.1.3 Navigation and position fixing functions

3.1.3.1 Area navigation (RNAV): The PCAAS shall provide RNAV referenced to VORTAC stations and also referenced to latitude/longitude* by pilot mode

*Stored on mass memory data base.

selection on the Integrated Data Control Center. The position status shall take the form of range and bearing relative to any of nine selected waypoints.

Waypoint zero shall be reserved for present position. Means shall be provided for initializing present position by entering a known latitude/longitude.

Provision shall be made to permit the pilot to insert any waypoint designated on the electronic "Jeppesen" airways maps as a reporting point, airport, NDB, or VORTAC station by entering a code of no greater than five numbers associated with the desired waypoint. The alphanumeric display on the IDCC (Integrated Data Control Center unit) will echo back the alpha identifier for the selected point.

Other waypoints may be selected by either designating the LAT/LNG of the desired point or the range and bearing relative to a specified VORTAC station.

The RNAV function shall provide the following flight status data:

- Present position in LAT/LNG coordinates to the nearest tenth of a minute.
- Range and bearing to any selected waypoint.
- Estimated time en route (ETE) to any selected waypoint.
- Estimated time of arrival to any selected waypoint.
- Ground speed.
- Wind speed and true direction.

Provision shall be made for updating present position (Waypoint zero) by reference to external position fixing means including but not limited to:

Key in of reference "fly-over" LAT/LNG position.

Weather radar in ground map mode using azimuth and range cursors.

The RNAV function utilizes the MCC for performing computation and shall utilize a dead reckoning mode which is updated by VOR/DME, DME/DME, and/or OMEGA based upon a Kalman filter algorithm. The dead reckoning update shall be at a cycle time of 5 sec or less.

The RNAV function together with the VNAV function shall provide the capability of executing FAA approved SID's and STAR's.

3.1.3.2 Vertical navigation (VNAV) function: The PCAAS shall provide a VNAV function which provides vertical steering to selected waypoints which are defined by three parameters: latitude (LAT), longitude (LNG), and altitude (ALT). The altitude parameter shall be compatible and consistent with the altitude encoder used with the DABS.

The VNAV system shall have two modes:

- Mode one provides for VNAV steering from the present altitude to the next selected waypoint which has an altitude designation.
- Mode two provides for VNAV steering from one selected waypoint with altitude designated to the next designated altitude.

A third functional use of VNAV is to provide a pseudo glide slope at airports not equipped with MLS GS or VHF GS. During this mode the GPWS plays a warning role.

The ascent or descent rate commanded by VNAV to fly the appropriate trajectory must take into account the aircraft flight envelope indications. If an unsafe or impossible altitude rate is required, the pilot shall be so advised by means of the System Status Display.

3.1.3.3 Landing approach function: The PCAAS shall provide automatic or manual-aided landing approach providing both lateral guidance and vertical guidance to a selected landing point. The landing approach function shall be available for all FAA approved approach procedures including but not limited to:

- VHF localizer approaches
- VOR approaches
- RNAV approaches
- VHF/UHF ILS approaches (LOC and GS)
- RNAV/VNAV approaches

When utilizing RNAV/VNAV laterally curved, multiple glide slope segment approaches shall be possible.

3.1.3.4 Inertial navigation function: The PCAAS shall not be required to provide an INS navigation mode; however, provision shall be made to interface with INS through the MCC I/O when necessary. However, additional hardware or software shall be provided to meet these provisions — only required for INS.

3.1.3.5 Auxiliary navigation functions: The PCAAS shall provide additional auxiliary navigation functions which provide pilot advisory information during en route navigation, in terminal areas, and during landing approach. These auxiliary functions shall include:

- Automatic direction finding utilizing LF and BC emitters in the 190 K Hz to 2 M Hz baud.
- Marker beacon for the 75 M Hz fan markers including the ability to respond to the three levels of audio modulation by either audio tones or coded colored lights.
- Navigation correlation cross-checks shall be performed utilizing functionally redundant navigation sensors including:
  - At critical intersections tune VOR Receiver No. 1 to check VOR No. 2 as a fix or waypoint is approached.
  - On final approach tune VOR/LOC Receiver No. 1 to check VOR/LOC Receiver No. 2.
  - At intersections use DME to check VOR designated intersections.

- Correlate localizer against ADF bearing approaching an outer marker with NDB.
- Check glide slope against altimeter and/or radar altimeter at outer marker and middle marker.
- Correlate glide slope vs. DME and altitude at approach facilities which have a terminal DME, e.g., SFO and LAX.

3.1.4 Automatic flight control functions.-The automatic flight control functions of PCAAS shall include necessary inner loop stabilization, attitude hold, RNAV/VNAV coupling, and approach coupling. The flight control computations shall be performed digitally utilizing the MCC with appropriate A-D and D-A signal converters.

The sampling rates shall be adequate to insure stability from a sampled data point of view. The use of predictive sampling technique to reduce the sampling rates and the MCC throughput requirements are strongly encouraged.*

There shall be not objectionable engage/disengage transients.

3.1.4.1 Lateral control modes: The PCAAS shall provide lateral control using ailerons and, if necessary, rudder control. The following lateral modes shall be provided:

a. Heading hold/set

   The PCAAS shall provide slaved magnetic heading hold. A heading set function shall be provided which permits the pilot to set in a desired magnetic heading. The PCAAS AFCS shall turn to the selected magnetic heading. Appropriate logic shall be included to maximize pilot acceptance. This shall include:

   - Small bank angles for small heading changes.
   - Smooth turn entry.
   - Consistent system operation for turns over 180 deg

*There has been a tendency in digital flight control systems to use very high sampling rates which impose unnecessarily high throughput requirements on the digital computer.

b. NAV coupling

The PCAAS shall provide coupling to all NAV subsystems. The NAV course deviation signals shall be utilized by the PCAAS AFCS to maintain a desired course. The steering function during NAV coupling shall have two modes of operation:

- Course-line which shall control the aircraft from its present position to a selected course line and controls along that course line to the next waypoint. This mode would be used when a waypoint must be approached along a designated course, e.g., during IFR approaches and for airway navigation.

- Present position which shall control the aircraft from its present position along a rhumbline or great circle segment to the next selected waypoint.

c. Localizer approach coupling

The PCAAS shall provide LOC coupling for landing approaches at airports with VHF localizer facilities. The error signal from the localizer shall be used to provide for capture and control along the selected localizer course. The LOC coupling mode shall have two phases

- Acquisition phase during which the AFCS localizer coupler issues appropriate heading commands to smoothly intercept the localizer course at any intercept angle.

- Control phase during which the AFCS localizer coupler maintains the aircraft on the localizer course by appropriate bank angle commands. The system shall have the capability of accommodating extreme shear wind conditions as specified in para. 3.3.4.1c.

d. Standard turn rate command

The pilot may select a standard rate (3 deg/sec) turn to the right or left by depressing a button on the IDCC panel.

e. Automatic lateral trim

The PCAAS shall provide automatic rudder trim for those aircraft requiring rudder control. The PCAAS shall provide automatic aileron trim for those aircraft requiring aileron trim actuator.

3.1.4.2 Pitch control: The PCAAS shall provide the following pitch control modes using the elevator for control.

a. Attitude hold

The PCAAS AFCS shall cause the aircraft to hold pitch attitude based on control column position.

b. Altitude hold

The PCAAS AFCS shall cause the aircraft to hold the pressure altitude existing when the mode is selected on the IDCC panel.

c. IAS hold

The PCAAS AFCS shall cause the aircraft to hold the indicated airspeed existing when the mode is selected on the IDCC panel.

d. VNAV coupling

The PCAAS AFCS shall utilize the VNAV altitude error signal to control the aircraft along the required ascent or descent flight path to cross the next waypoint at the designated pressure altitude. The flight path trajectory will be such that a constant rate of climb or descent is commanded through pitch control.

In the event that an unsafe or impossible altitude rate is commanded, the mode shall be decoupled and the pilot notified by means of a status panel light and an audio signal.

The VNAV coupler may be used to provide a synthetic glide slope at airports not equipped with VHF glide slope facilities.

e. Glide slope (GS) coupling

The PCAAS AFCS shall utilize the deviation signal from the VHF GS receiver to provide pitch control during landing approach. The glide slope coupling mode shall include two phases:

- Acquisition phase during which time the aircraft is in altitude hold until the GS deviation is within one-half degree of centerline at which time GS control is selected.
- GS control during which time the aircraft is controlled along the glide slope. The PCAAS GS coupler shall accommodate extreme wind shears.

3.1.4.3 Stability augmentation: The PCAAS AFCS shall provide for modification of the basic aircraft modes to insure desirable handling qualities in all axes. The following functions may be appropriate:

- Damping of the spiral mode to allow hands off flight.
- Damping of the dutch roll mode where deficiencies adversely affects aircraft handling, ride comfort, or autopilot performance.
- Damping of the roll mode where necessary. (Aircraft with wing mounted engines and tip tanks are likely candidates.)

There is no requirement for the PCAAS AFCS to provide stability augmentation to the aircraft short period mode. However, no serious degradation in short period stability shall result from the implementation of the pitch control modes.

Positive damping of the aircraft phugoid modes shall be provided during pitch control modes.

3.1.4.4 Throttle control: There is no requirement for throttle control for the PCAAS AFCS; however, provision shall be made for adding throttle control.

3.1.5 <u>Controls and displays functions</u>.-The PCAAS shall provide integrated controls and displays functions to provide for pilot and system data entry and data display and readout for all PCAAS functions and modes. The PCAAS controls and displays provide the basic communications between the pilot and PCAAS utilizing the MCC I/O and computations as well as the controls and displays subsystems for the pilot/PCAAS interface.

3.1.5.1 Data entry and display: The Integrated Data Control Center (IDCC) specified in para. 3.2.2 shall provide essentially all data entry functions for PCAAS and represent the principle mode of communication between the pilot and the PCAAS. The IDCC functions include:

- Communication mode select, data insertion, and display
- Surveillance mode select, data insertion, and display
- Navigation mode select, data insertion, and display

a. Data entry

A data entry panel suitable for entering PCAAS data shall be provided which includes numerical and special function keys. When appropriate, multiple sequence keys may be used to define special functions in order to conserve panel space.

Typical data to be entered is summarized in Table 3.1.5.1-1. This data table is not intended to be complete but is representative of the types of data which can be entered by the data entry panel.

The data entry panel must provide the pilot with unambiguous cues as to which modes have been selected, which data has been entered, and what sequence of data entry is required. Such cues may be visual, audio, and/or tactile.

The arrangement of the IDCC data entry panel must be such that new functions and modes may be added or existing ones deleted without requiring hardware changes to the IDCC. Such changes shall be implemented by software (firmware) changes only.

b. Digital data display

Means shall be provided for displaying data being entered from the data entry panel as well as PCAAS computed data. The data being displayed shall be annotated in an unambiguous manner using display fields. Table 3.1.5.1-2 summarizes typical data required for display. This list is not intended to be complete. The same units are used as in Table 3.1.5.1-1.

c. Mode selection

MCC aided cueing will be utilized to define the data input requirements for each selected mode. Also when there are several alternate submodes available, the pilot will be offered the choices for selection.

TABLE 3.1.5.1-1. TYPICAL DATA ENTRY PANEL DATA

ENTRY PARAMETER	UNITS	NO. DIGITS
Command altitude	ft	5
Baro setting	in. Hg	4
Command airspeed	kt	3
Command climb rate	fpm	2
Command heading	deg	3
VOR LOC system select		1
VOR LOC channel select	mHz	5-1/2
VOR LOC channel store	discrete	1
RNAV waypoint bearing	deg	3
RNAV waypoint range	N mi	4
RNAV waypoint latitude	deg/min	5 + N/S
RNAV waypoint longitude	deg/min	6 + E/W
RNAV waypoint altitude	ft	4
RNAV waypoint store/select	no. + discrete	2
Fuel on board	gal	4
Range to destination	N mi	4
Fuel flow rate	gal/hr	3
Time	hr/min/sec	6
Passenger weight and position	lb/location code	3 + 1
Baggage weight	lb	3
Outside air temperature	^{o}F	3 + sign
Runway altitude	ft	5 + sign
Flight plan leg number	0-99	2
Flight plan range to destination	N mi	4
Flight plan bearing to destination	deg	3
Flight plan wind direction	deg	3
Flight plan wind speed	N mi	2
Flight plan altitude	ft	5
Flight plan airspeed	kt	3
Voice channel select	mHz	5-1/2
Call up voice channel	no.	2
Data channel frequency select	mHz	5-1/2

TABLE 3.1.5.1-2. TYPICAL DIGITAL DATA DISPLAYED

ENTRY PARAMETER	NO. DIGITS
VOR DME range to station	3
VOR DME bearing to station	3
VOR DME speed	3
Fuel remaining	4
Fuel remaining at selected waypoint	4
Range remaining	4
Range remaining at selected waypoint	4
Optimum rpm and manifold pressure for MAX range	4
Optimum rpm and manifold pressure for MIN range	4
ETE/ETA at selected waypoint	6
Distance to selected waypoint	4
Center of gravity	6 + sign
Wind speed	2
Wind direction	3

d. Readability

The digital data displays and mode legends shall be easily readable under all cockpit lighting and viewing conditions. As a guideline to readability, the following goals are specified:

(1) The alphanumeric legends shall be visible in a background ambient of 10,00 ft lamberts and by night panel illumination.

(2) The alphanumeric characters shall subtend a visual angle of 15 mrad at a viewing distance of 24 in.

3.1.5.2 Flight situation display: The PCAAS shall display flight situation information suitable for manually controlling the aircraft during IFR flight. The basic flight situation information shall include:

- Aircraft pitch and roll attitude portrayed by a horizon symbol.
- Aircraft magnetic heading.
- Aircraft roll angle.

In addition to the basic flight situation information, auxiliary flight information pertinent to the phase of flight shall be displayed including:

- Angle of attack
- Indicated airspeed
- Pressure altitude
- Radar altitude
- Glide slope
- Localizer/VOR

3.1.5.3 Navigation Map Display: The PCAAS shall provide a Navigation Map Display which displays a selected Jeppesen chart segment for en route, terminal area, approach, SID and STAR navigation. Provision shall be made for the pilot to select an adjacent chart segment by depressing a momentary up/down/right/left switch.

a. Scale expansion

The chart displayed shall be decluttered such that only vital navigation information is displayed. The navigation maps shall be displayed with north up. A moving aircraft symbol shall be utilized to portray the aircraft location on the map. An option of displaying the octant nearest to the aircraft heading shall be provided.

Key navigation points shall be portrayed by an appropriate symbol together with a three or five letter designator followed by a five number code. The code allows the pilot to designate any navigation point by entering the five number code on the IDCC keyboard. Such navigation points shall include airports, NDB, VORTAC, and reporting points.

The navigation map shall be switched automatically as the mvoing aircraft symbol approaches the boundary of a map segment. The aircraft symbol shall be "flashed" just prior and just after switching map segments to aid in finding the aircraft symbol.

3.1.5.4 System status annunciation functions: The System Status Display panel shall provide status and warning indications for the pilot when cautionary or unsafe situations are present or are predicted to arise if corrective action is not taken. The System Status Display shall use a combination of lights, lighted legends, colors, and audio cues to warn the pilot of an existing or insipient unsafe condition.

The unsafe conditions shall include discrete events such as altitude too low or sink rate too high on approach, as well as MCC derived correlation factors such as large navigation position discrepancies between VOR/DME Receiver No. 1 and VOR/DME Receiver No. 2.

The computation associated with the flight status correlation subsystem shall provide the appropriate logic to drive the system status display panel caution and unsafe condition cues.

Consideration shall be given to the use of recorded words or stored "phonemes" to synthesize spoken word warnings such as "you are too low." Such a capability is considered an option for the Intermediate system.

3.1.5.5 Aircraft configuration display: A display means for depicting the configuration of the aircraft shall be provided for the following conditions:

- Landing gear position
- Wing flap position
- Cowl flap position

The configuration display shall be viewable under all cockpit lighting conditions.

The flight status correlation subsystem shall use the data provided to the aircraft configuration display to determine unsafe conditions, for example: gear up with radar altitude less than 500 ft and speed in the landing approach IAS region.

3.1.5.6 Hard copy printout function: The PCAAS shall have provision for adding capability for a hard copy printout to print selected messages from data memory. The printer shall have alphanumeric capability and shall print at a rate of at least 110 characters per second with a column width of 32 characters. The printer shall be capable of printing any message which may be stored in memory upon command from the IDCC. Certain messages will be automatically printed such as ATC clearances and engine maintenance diagnostics.

3.1.6 Flight management functions.-The PCAAS flight management functions shall provide the pilot with status information necessary to assist a single pilot in the conduct of safe flight in a dense traffic environment.

3.1.6.1 Flight plan entry data: PCAAS shall provide a means for entering prestored data such as flight plan data and "electronic Jeppesen" charts to allow for rapid data entry of flight planning data. This function provides an alternate to avoid keying in vast amounts of data from the keyboard. Such mass data entry means must provide the capability of loading data in modular form. A minimum of 800,000 bits of storage should be available for each module which provides up to 50 "pages"* of data.

*A page is defined as 25 lines of 80 characters per line (2000 characters).

3.1.6.2 Aircraft performance calculations: The aircraft performance data specified in the standardized GAMA operating handbook shall be programmed into the PCAAS MCC thereby allowing the pilot immediate access. Specifically this perofrmance data shall include:

- Stall speeds vs. weight
- Takeoff distance
- Accelerate-stop distance
- Best rate and angle of climb speeds
- Single engine service ceiling
- Time, fuel, and distance to climb to predetermined altitude
- Range
- Endurance.
- Time, fuel, and distance to destination
- Landing distance
- Maximum glide performance speeds

Because many performance curves are based on calculations, a flight test procedure shall be specified to calibrate the output of PCAAS.

The above data shall be accessible by other PCAAS modes for in-flight calculation of such items as remaining range at various power settings, etc.

3.1.6.3 Fuel management: The PCAAS shall maintain complete fuel status information using stored and sensed data. Provision shall be made to utilize stored parameters which are manually entered in the event that the aircraft does not utilize sensors for the required parameter. However, accurate measurement of fuel at reasonable cost will be a PCAAS goal.

The input parameters utilized by the fuel management functions shall include:

- Fuel quantity (within 5 min of flight time at maximum cruise power)
- Fuel flow rate (within 1 percent)
- Ground speed

The amount of fuel and time remaining in each tank shall be displayed to the pilot. An aural and visual warning will alert the pilot when a tank is about to run dry.

The fuel management function utilizes the MCC and the above parameters to compute the following reserves:

a. Fuel reserve in gallons

The computation provides the fuel reserves in gallons at any selected waypoint. The computation shall be based upon the fuel remaining less the fuel used at the current fuel flow rate during the estimated time en route to the selected waypoint. An automatic fuel state warning will occur if less than the specified reserves are forecast for the destination.

b. Fuel reserve in miles

The computation provides the fuel reserves in nautical miles for any selected waypoint. The computation shall be based upon the number of miles to the waypoint, the ground speed corresponding to the current computed wind, and the fuel predicted to be remaining at the waypoint.

c. Fuel reserve in hours

The computation provides the fuel reserves in hours for any selected waypoint. The computation shall be based upon the ETER to the waypoint, the fuel remaining at the waypoint, and the current fuel consumption rate.

In the event that a flight plan is stored in the MCC, then the reserves will be based upon the parameters of the flight plan legs which include the selected waypoint. Otherwise, a great circle distance computation will be used.

Finally the fuel reserves for any selected power setting may be obtained by entering the new power setting on the keyboard. This will allow the pilot to evaluate the effect of changing power on his fuel reserves as well as his time to destination (also computed).

3.1.6.4 Weight and balance: PCAAS shall have provision for adding the capability of using a combination of strain gauges on each landing gear and pitch attitude to calculate the aircraft weight and c.g. location on the ground. These parameters shall be updated during flight based on fuel burnoff. Out of limit conditions shall be displayed to the pilot. Normal procedure is to use parameters which are keyed in by the pilot for the weight and balance computations.

3.1.6.5 Emergency functions: This mode recognizes the fact that the pilot needs certain information quickly and accurately in emergency conditions.

a. Nearest alternate

By pressing a single button, PCAAS will compute the course, time, fuel, fuel reserves, and best power setting for minimum time or minimum fuel to the nearest airport. Also displayed will be the runway length, type approach aids, and lowest minima for that airport. By sequentially depressing the "nearest alternate" button the pilot will get the above information on increasingly distant airports. The criteria for establishing priorities shall include the currently computed wind.

b. Single engine best rate of climb speed

If an engine (on a multiengine airplane) fails, PCAAS shall compute the appropriate indicated best single engine rate of climb speed (V_{YSE}) for the current weight, temperature, and pressure altitude. This will be displayed by a bug on the airspeed indicator which will be automatically slow to V_{YSE} if the PCAAS engine management system senses an engine failure.

c. Go/no go decision

If one engine of a multiengine airplane fails and PCAAS computes that a positive rate of climb is not possible, an abort command shall be displayed. If at altitude, the pilot can override this command and PCAAS will display the single engine service ceiling at the current weight, temperature, and power setting as well as the range to ground impact for a specified field elevation.

3.1.7 Engine management functions.-The PCAAS engine management system shall provide the pilot with the necessary information to operate the aircraft engine(s) with a minimum use of fuel while maintaining adequate cooling at all flight conditions. Protection against overcooling some cylinders during descent shall be provided.

3.1.7.1 Optimal engine power setting and monitoring: The PCAAS shall provide a number of functions to aid the pilot in optimal engine power management and monitoring. These functions are summarized:

a. Power settings

The PCAAS engine management system is based on the fact that the pilot usually selects the percent horsepower based on a desired true airspeed, fuel consumption rate, and an engine rpm selected for smoothness and cabin noise. Given the desired percent power obtained from the flight management subsystem and selected engine rpm, PCAAS computes the required manifold pressure and mixture control settings. The manifold pressure command is displayed via a bug on the manifold pressure gauge. A separate mixture control command indicator shall be provided.

b. Mixture control

The mixture command indicator shall indicate only whether the mixture is too rich or too lean for a given engine operating condition (e.g., pilot simply keeps the needle centered). Mixture control shall be based on EGT measurements. The control laws will minimize fuel consumption while insuring that engine temperatures are kept within limits. Pilot displays and controls will be designed to allow near optimum engine operation even during high workload situations involving numerous power changes.

c. Engine synchronization

The engines shall be automatically synchronized with the right engine rpm being slaved to the left engine. Failure or sudden changes in rpm on the left engine will result in a synchronization cutout. (The right engine will not stop because the left engine fails.)

d. Optimum engine management

Upon command from the keyboard, the pilot will be able to determine the appropriate relationship between manifold pressure, rpm, true airspeed, altitude, and fuel flow to make intelligent decisions regarding optimum engine operation for various flight situations. More specifically, the following functions will be available:

- Miles per gallon in terms of true airspeed.
- Power setting and altitude where miles per gallon can be maximized for a given true airspeed.
- Optimum climb/descent power settings for a given trip length. Winds will be accounted for if entered or otherwise computed by PCAAS.

3.1.8 Engine health.-The PCAAS shall provide for thorough monitoring of engine health to enhance safe operation and to aid in preventive engine maintenance. Such monitoring is expected to significantly reduce the probability of a catastrophic engine loss due to mismanagement of the power plant.

Engine health diagnostics shall be based on continuous measurement of the following parameters:

EGT for each cylinder

Fuel flow

Cylinder head temperature for each cylinder*

Oil supply level*

Oil temperature*

Oil pressure*

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*These parameters are options not included in the Intermediate system.

Manifold pressure

RPM

Turbine inlet temperature*

Engine compartment temperature*

Generator or alternator voltage and amperage*

A brief summary of how each parameter will contribute to the health monitoring function is given in the following paragraphs.

a. Oil temperature and pressure†

The measured oil temperature and pressure are compared with reference values to determine if the values are within the normal ranges. The normal values are functions of:

RPM
Manifold pressure
Outside air temperature
IAS

b. EGT trends

The EGT trends for each cylinder shall be stored and compared with preprogrammed diagnostics to determine when changes indicate preventive maintenance action is called for. Such diagnostics shall take into account power and mixture control setting changes to avoid false alarms. EGT trend diagnostics which are presently envisioned are summarized in Fig. 3.1.8-1. (While the effects shown in this figure are known to exist, there may not be any concrete data available to quantify the preprogrammed diagnostics. Therefore, engine tests may be required before the EGT trend diagnostic routine could be implemented. Without such data the level of discrimination possible for different type failures cannot be determined.)

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*These parameters are options not included in the Intermediate system.
†This function is an option only for the Intermediate system.

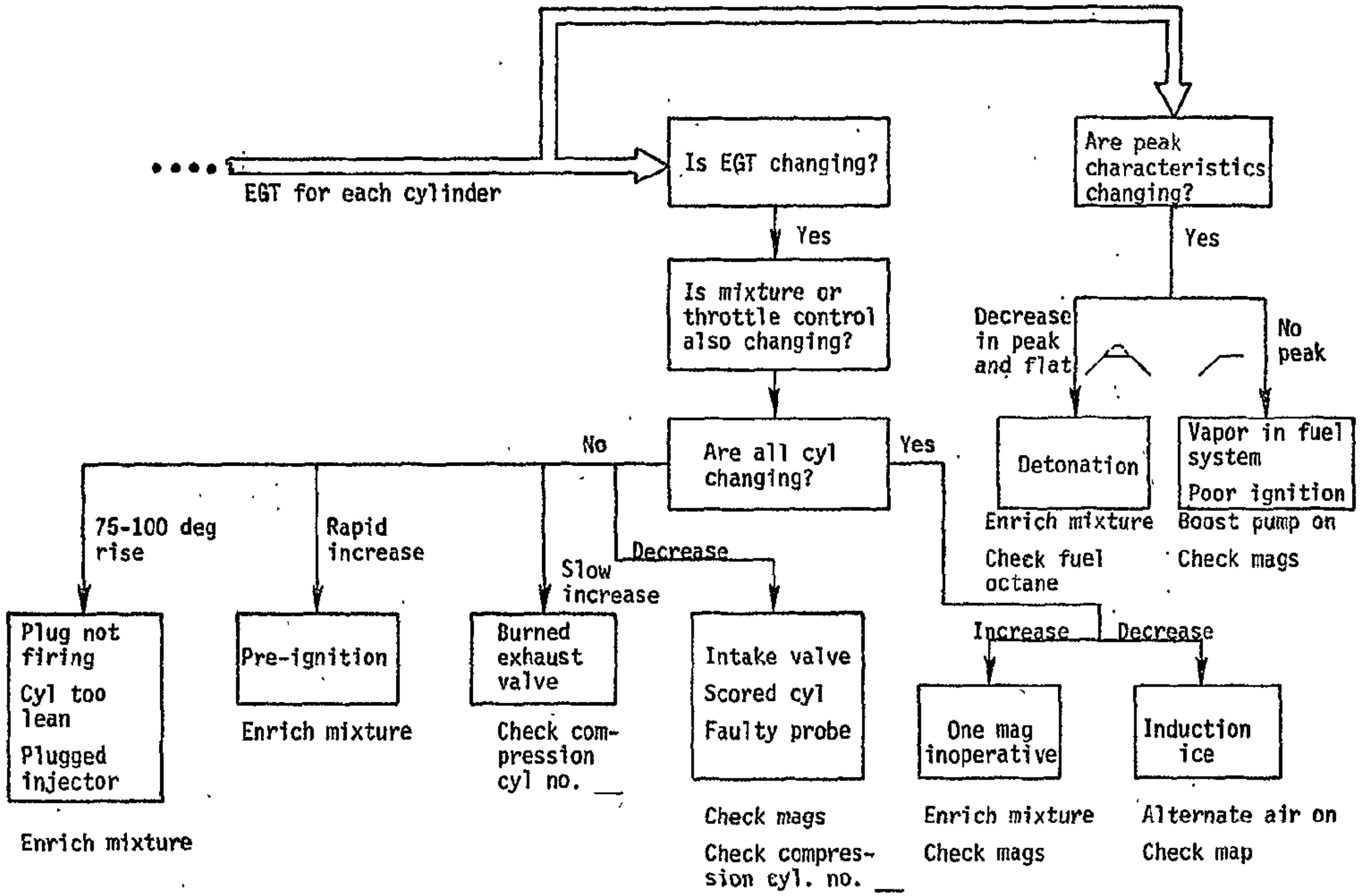

Figure 3.1.8-1. EGT Trend Diagnostics

c. Cylinder head temperature (CHT) trends*

The CHT trends shall be compared with preprogrammed diagnostics to determine preventive maintenance actions required.

d. Electrical power system*

The alternator (or generator) and voltage regulator outputs and battery voltage shall be monitored to determine proper operation of the aircraft electrical power system. Discrepancies noted will cause caution or warning displays on the system status display.

e. Engine compartment temperature*

Engine compartment temperatures shall be monitored to determine overheating conditions or fire with appropriate warnings displayed to the pilot.

f. Oil supply*

The oil supply quantity and the existence of metal particles in the oil screen shall be monitored with appropriate warnings displayed to the pilot.

g. Fuel flow

The fuel flow shall be monitored to detect low fuel or foreign object blockage of the fuel lines. Also fuel flow and EGT shall be compared to improve the ability to correctly diagnose engine problems.

h. RPM and manifold pressure

RPM and manifold pressure shall be checked to insure that engine limits are not exceeded.

Engine health diagnostic shall be displayed on the System Status Display in terms of problem isolation and corrective action, e.g., as shown in Table 3.1.8-1.

3.1.9 Flight status correlation.-Table 3.1.9-1 summarizes typical information from the flight status correlation functions which will be displayed on the System Status Display.

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*These functions are options only for the Intermediate system.

TABLE 3.1.8-1. ENGINE HEALTH DIAGNOSTICS

PROBLEM	CORRECTIVE ACTION
Normal	None
Preignition Cylinder No. __	Enrich mixture
Low EGT Cylinder No. __	Check mags
Low fuel pressure	Switch tanks Boost pump on Mixture rich
High EGT Cylinder No. __	Enrich mixture Check mags
Low EGT all cylinders	Increase man pressure
Propeller overspeed	Check oil pressure Reduce power Reduce rpm
High oil temp	Open cowl flaps Increase speed Reduce power
High Cylinder Temp No. __	Open cowl flaps Increase speed Reduce power Check EGT No. 6
Engine fire	Close vent shutoff Mixture — idle cutoff Fuel — off Battery switches off Mags off
Generator overcharge	Gen field off
Generator discharge	Minimize electrical load
Low oil quantity	Land immediately
Metal chips in oil	Land immediately
Large EGT spread	Identify cylinder — fix
Low Cylinder Temp No. __ (shock cooling)	Increase map Close cowl flaps

TABLE 3.1.9-1

FLIGHT STATUS CORRELATION ANNUNCIATOR LEGENDS

PROBLEM	CORRECTIVE ACTION
Door open	Normal landing
Gear inoperable	Circuit breaker — off Gear handle — down Manual crank — 50 turns Check — light-indicator horn
Engine failure	Max glide — 105 kt Flaps — up Cowl flaps — closed Prop — low rpm Gear up Switches off
Tank No. 1 running dry	Switch tanks
Altitude too low	Climb
IAS exceeds safe limits	Slow down
Gear up during landing approach	Extend gears
Discrepancy between dir gyro and mag compass	Set dir gyro
Rate of climb low	Advise ATC of climb problem
IAS too low for power setting	Clean up aircraft configuration

Annunciator messages shall be assigned priorities such that only complementary messages shall appear at one time. For example: If an engine fails, the engine shutdown checklist shall appear. Other items which are a consequence of the engine failure (low rate of climb, zero fuel flow, etc.) shall not appear. Complementary messages shall appear. For example: if a door opens on takeoff, the appropriate message will appear. In the event that the door distracts the pilot so that he lets his speed decay or forgets to lower the landing gear, the additional messages shall appear in order of priority.

3.2 PCAAS Subsystems

The PCAAS system architecture consists of the following subsystems:

- Microcomputer Control Complex subsystem
- Controls and displays subsystem
- Flight status correlation subsystem
- Engine health status subsystem
- Flight management subsystem
- Communications subsystem
- Surveillance subsystem
- Navigation and position fixing subsystem
- Automatic flight control subsystem
- Microcomputer Control Complex software subsystem

The Microcomputer Control Complex (MCC) subsystem provides all the computation functions for the PCAAS subsystems in several functional modules as indicated. All communications between subsystems occur by means of digital data transfer between the functional elements of the Microcomputer Control Complex.

The communication between the pilots is primarily through the controls and displays subsystem. However, the pilot also communicates through the sensors and switches of the AFCS.

3.2.1 Microcomputer Control Complex subsystem (MCC).-The Microcomputer Control Complex shall be implemented using advanced microprocessor technology available in 1977. The MCC shall consist of the following system elements:

- Central Processing Units (CPU's)
- Read Only Memory (ROM) for storage of program memory and fixed constants
- Random Access Memory (RAM) for data storage and scratch pad registers (volatile)
- Electrically Alterable ROM (EAROM) for storage of program memory and calibration constants which may require change from system to system (nonvolatile)
- Programmable I/O devices and digital data bus interface for intra-subsystem communications

3.2.2 Control and displays subsystem.-The controls and displays subsystem shall consist of the following control and display subsystem units (C&DSU's):

- Flight Situation Display (FSD)*
- Navigation Map Display (NMD)
- Integrated Data Control Center
- System Status Display*
- Aircraft Configuration Display*
- Hard copy printer (option)
- Synthesized voice annunciator (option)

All these units are separate physically and each is a separate replaceable unit except for those denoted by asterisk. These displays timeshare the NMD surface.

All units shall interface directly to the microcomputer complex rather than to exterior sensor or control elements. Each unit shall have adequate symbol generation and memory capability to insure adequate isolation of the pilot interface and microprocessor interface requirements.

3.2.2.1 Integrated Data Control Center unit modes: The Integrated Data Control Center unit is a mode control system which provides a selection tree which reminds the pilot of the data to be entered, and displays the actual data entered.

a. Communication

When this mode switch is depressed, the alphanumeric display reads the channel frequency currently selected. A second depression of this switch indicates the channel frequency stored. A third depression brings up the third stored, and so forth for ten storage locations. This scanning mode does not switch the current operating frequencies. To change operating frequency, the enter switch must be depressed while the channel frequency is displayed. Changing selected channels is performed by keying in a selected frequency. The appropriate system is selected by depressing the appropriate legend.

b. Navigation

When this mode switch is depressed, the following submode legends appear: Heading, Altitude. If Heading is selected, the following submodes appear: VOR LOC, RNAV. If VOR LOC is selected, the alphanumeric display indicates the current NAV channel selected. Insertion of channel selection data is then identical to that for selecting communications data. If RNAV is selected, Range and Bearing appear on the alphanumeric legend. The pilot then inserts this data in that order. Ten waypoints can thus be entered by continuing to depress the RNAV legend.

If the altitude mode is selected in the original navigation selection, the following sublegends appear: Glide Slope, VNAV. Selecting glide slope causes the steering index on the Flight Situation Display to indicate glide slope deviation. Selecting VNAV causes the steering cursor on the Flight Situation Display to indicate steering. A sublegend will appear: Pitch. The pilot then inserts the pitch angle command and depresses the ENTER switch.

c. Flight management

An appropriate set of flight management system modes shall be provided.

3.2.3 Flight status correlation subsystem (FSCS).-The FSCS consists of a number of sensors plus the appropriate computation functions provided by MCC. The sensors include:

- TAS sensor
- Outside air temperature sensor
- Pressure altitude sensor
- Landing gear position switch
- Flap position sensor
- Magnetic heading sensor
- Cowl flap position indicator
- Rate of climb indicator
- Battery voltage sensors

The information shall be displayed on the NMD display surface.

3.2.4. Engine health status subsystem (EHSS).-The EHSS consists of a number of sensors plus the appropriate computation functions provided by MCC. The sensors include:

- EGT sensors
- CHT sensors
- Etc.

3.2.5 Flight management subsystem (FMS).-The FMS consists of a magnetic tape cassette which provides flight planning data, the fuel quantity sensors, and the fuel flow rate sensors plus the appropriate computation functions provided by the MCC.

3.2.6 Communications subsystem (CS).-The communication subsystem consists of dual 720 channel VHF transceivers, the associated antennas, speakers, microphones, and headsets and the appropriate computation provided by the MCC.

3.2.7 Surveillance subsystem (SS).-The SS consists of the DABS beacon, altitude encoder, radar altimeter, ancilliary ELT, weather avoidance sensor, the associated antennas, and the appropriate computations provided by MCC.

3.2.8 Navigation and position fix subsystem (N&PFS).-The N&PFS consists of dual VHF VOR/localizer receivers, OMEGA receiver, dual DME's, ADF, marker beacon receiver plus the associated antennas and the appropriate computation provided by the MCC.

3.2.9 Automatic flight control subsystem (AFCS).-The AFCS consists of rate gyros, accelerometers, attitude sensors, control wheel steering sensors and switches, trim actuators, surface actuators, and the appropriate computations provided by MCC.

3.3 PCAAS Performance

3.3.1 Communications performance

a. Voice

PCAAS shall provide the capability to reliably communicate over VHF voice channels for a minimum range of 100 N mi with 150 N mi desired, when at the minimum en route altitude (MEA).

b. Digital data broadcast

PCAAS shall have the provision to add the capability to receive and transmit digital data over the VHF channels at a serial data rate of 9600 baud. The range for digital data shall be the same as the range for voice.

c. DABS digital data

PCAAS shall have the provision to add the capability for receiving and transmitting digital data using DABS at a serial data rate of 256 K baud.

3.3.2 Surveillance performance

a. Transponder

PCAAS shall have the provision to add a DABS transponder with a power output of at least 100 watts and shall meet TSO Class 2B standards as a minimum. The Intermediate system shall provide an ATC transponder with a PK power of 275 watts and shall have both A and C mode capabilities.

b. Altitude encoding

PCAAS shall provide automatic altitude reporting to an accuracy of ±125 ft, $2\sigma^*$. The altitude encoder shall meet the requirements of TSO C88.

c. Ground proximity warning

PCAAS shall provide ground clearance up to an altitude of 1000 ft with $2\sigma^*$ accuracy of 5 ft or 5 percent whichever is largest at low altitude. The response time for altitude measurement shall not exceed 0.1 sec.

d. Weather avoidance

PCAAS shall provide weather avoidance data to the pilot accurate to within ±2-1/2 deg over an azimuth sector of 90 deg or greater. The PCAAS weather avoidance shall detect weather cells out to a range of at least 100 N mi.

e. ELT

PCAAS shall include an ancilliary emergency locator transmitter which complies with TSO 091, Reference RTCA DO-145.

3.3.3 Navigation and position fixing performance

a. RNAV

PCAAS shall provide RNAV accuracy which complies with FAA AC-90-45 (ARINC Characteristic 582). Slant range correction shall be provided.

b. VNAV

PCAAS shall provide VNAV $2\sigma^*$ accuracy of ±50 ft below 1000 ft and $2\sigma^*$ accuracy of ±100 ft above 1000 ft above ground level. PCAAS shall be capable of maintaining a flight path angle within 0.1 deg.

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*2σ is specified to provide 90 percent probability of having an error less than specified.

c. Landing approach

PCAAS shall provide landing approach guidance accuracy compatible with the approach procedure being utilized.

3.3.4 Automatic flight controls performance

a. Stability augmentation

PCAAS shall provide stability augmentation such that the augmented aircraft stability is equal to or better than the aircraft stability without AFCS. The spiral mode shall have positive stability.

b. Lateral control

PCAAS shall provide heading control within 0.5 deg $2\sigma^*$ accuracy of the heading sensor.

PCAAS shall provide roll control within 0.5 deg $2\sigma^*$ accuracy of the roll sensor.

PCAAS shall provide a commanded turn rate within ±10 percent of the command value.

PCAAS shall provide RNAV/VOR control such that the AFCS does not contribute a standoff error greater than 10 percent of the total error.

c. Pitch control

PCAAS shall control pitch attitude within 0.5 deg $2\sigma^*$ accuracy of the attitude sensor.

PCAAS shall not cause an altitude standoff error greater than 50 ft ($2\sigma^*$).

PCAAS shall hold IAS within ±2.5 kt $2\sigma^*$ accuracy of the IAS sensor.

PCAAS shall hold angle of attack within 0.5 deg $2\sigma^*$ accuracy of the angle of attack sensor.

3.3.5 Controls and displays performance

a. Viewability

All PCAAS displays and lighted switches shall be viewable under a cockpit illumination of 10,000 ft-lamberts (bright incident sunlight). Furthermore, PCAAS shall provide a cockpit dimming control to permit reducing display illumination at night. The night lighting shall be either red or lunar white.

$^*2\sigma$ is specified to provide 90 percent probability that the error is less than specified.

b. Size and resolution

The size and resolution of all PCAAS displays shall be such that the legends, symbology, and alphanumeric notations are easily viewable at an eye distance of 24 in. by individuals with corrected 20/20 vision and are of acceptable quality to experienced pilots.

c. Touch temperature

All PCAAS controls and displays shall have a touch temperature low enough to touch without gloves or other protective material being required.

d. Parameter resolution

All displayed parameters shall have resolution adequate to the accuracy and use of the parameter.

3.3.6 Flight management performance

a. Fuel reserves

PCAAS shall compute and display fuel reserve quantities within ±2.5 percent accuracy (2σ).

b. Weight and balance

PCAAS shall provide for gross weight measurement within ±2.5 percent accuracy (2σ) and center of gravity computation within ±2.5 percent accuracy (2σ).

3.3.7 Engine health/management performance

a. Engine performance

PCAAS shall provide computations for engine performance which shall be within ±2 percent of the corresponding handbook values.

b. Engine health

PCAAS shall predict engine health with a confidence factor of 95 percent.

3.3.8 Flight status correlation performance

a. Instrument cross-checks

PCAAS shall issue a pilot warning when there is a discrepancy of more than ±5 percent between the sensed parameter and the computed parameters.

b. Aircraft configuration cross-checks

PCAAS shall detect a discrepancy between flight phase and aircraft configuration with a confidence factor of 95 percent.

c. Aircraft operation cross-checks

PCAAS shall issue a warning when the aircraft operating parameter differs from the operational limit or ATC assigned parameter in excess of ±2 percent, providing the condition persists for more than 30 sec.

3.3.9 MCC data processing

3.3.9.1 Software structure: Those data processing and control functions that are required for flight safety shall be redundantly resident in at least two CPU's, one primary and one backup. The backup will be activated on failure of primary. These functions include, but are not limited to:

System status annunciation (para. 3.1.5.4)

Fuel reserve status (para. 3.1.6.3)

DABS data link (para. 3.1.1.2.2) (provision only)

ATC radar beacon (para. 3.1.2.1)

Intermittent positive control (para. 3.1.2.2) (provision only)

Ground Proximity Warning system (para. 3.1.2.4)

Landing approach (para. 3.1.3.3)

3.3.9.2 Memory reserve requirements: Memory capacity (ROM, EAROM, RAM) shall include reserve of 25 percent to allow for expansion or revision of functions.

3.3.9.3 Speed reserve requirements: Data processing time analyses shall be made for each of the data processing subsystems. Time alloted for the completion of each functional task shall include a time reserve of at least 25 percent.

3.4 PCAAS Maintainability

3.4.1 Maintenance concept.-The PCAAS maintenance concept shall consist of the following levels:

- Line replaceable units (LRU's) replaced on aircraft.
- Shop replaceable units (SRU's) replaced and later repaired at the FBO avionics shop.
- Critical component repair at the factor in such elements as gyros, actuators, power supplies, and other components beyond the normal repair capability of the avionic shop.

The PCAAS design and installation shall be such that each LRU is easily accessible from the cockpit or avionics equipment bay in the case of large twins. It shall not be necessary to remove one LRU to gain access to another LRU.

The avionics shop is expected to stock LRU and SRU spares based upon the failure rate of the items.

3.4.2 Mean-time to repair.-The mean-time to remove and replace an LRU in the aircraft shall be 10 min.

The mean-time to remove and replace an SRU in the avionics shop shall be 30 min.

The mean-time to repair a critical component at the factory shall be 60 min labor time.

3.4.3 Failure isolation

a. LRU isolation

THE PCAAS MCC shall provide the capability for LRU failure isolation by use of special diagnostic tapes which can be loaded into MCC memory through the flight management subsystem tape cassette. The hard copy printer of the controls and displays subsystem shall be used to print out a maintenance record in response to the diagnostic tests commanded by the diagnostic tapes.

The diagnostic tape shall have a probability of isolation to one LRU of 80 percent and to two LRU's of 95 percent.

b. SRU isolation

A hot mockup of the PCAAS MCC shall be used as an avionics shop test set for SRU failure isolation by use of diagnostic tapes.

The diagnostic tape shall have a probability of isolation to one SRU of 80 percent and to two SRU's of 95 percent.

3.5 PCAAS Reliability

3.5.1 Functional redundancy.-The PCAAS system architecture shall be organized to provide functional redundancy such that no single failure can cause the loss of a critical system function or subfunction. Examples of the functional redundancy include:

- Dual communication radios
- Ability to communicate over the DABS data link to ATC in the event all communication radios are lost
- Dual navigation radios
- Ability to perform RNAV using
  - Dead reckoning plus update
  - Single VOR/DME
  - Dual DME
  - OMEGA
  - Combination of above
- Backup of critical software modules in more than one MCC CPU and associated program memory
- Electronic displays with mechanical display backup

3.5.2 Mission reliability.-The PCAAS functional redundancy shall assure that the probability of completing a four hour IFR flight without loss of ATC communication and navigation shall be 0.999.

3.5.3 Mean-time before failure.-PCAAS shall have a goal for the system mean-time before failure (MTBF) to be 50 hours or greater. Note: This MTBF implies some maintenance action is required, not that the complete system is inoperable.

3.5.4 Environmental requirements

a. Shock and vibration

The PCAAS system elements shall be mounted such that the normal vibration and shock levels encountered in a general aviation aircraft will not cause failure.

b. Temperature

The PCAAS system elements shall operate over an ambient temperature range of 0 to 70° C. The PCAAS system shall not be damaged by ambient temperatures in the range of −55° to 125° C while nonoperating. Provision shall be made to interlock operation of the system when the temperature is outside the operating range.

3.6 PCAAS Interface

3.6.1 Electrical power.-PCAAS shall be powered with a 12 volt dc or 24 volt dc power supply. Adequate regulation shall be provided to permit primary voltage variations of ±20 percent from the nominal voltage. The PCAAS power supplies must have adequate regulation such that the power voltage to PCAAS circuits varies less than 1 percent. Loss of primary electrical power shall cause a warning to be issued. A standby power source must be provided to allow for 10 min emergency power to allow for flight critical PCAAS elements to function including one communication transceiver and one VOR receiver.

3.6.2 MCC volatile memory protection.-PCAAS shall provide means for protecting the MCC data memory from loss of critical flight parameters. The MCC data memory must be capable of retaining information for a minimum of 24 hours after the primary power is shut down.

3.6.3 Serial digital interface.-PCAAS shall have provisions for a serial digital data interface to permit serial data exchange between peripheral elements and the MCC as well as intra MCC data exchanges. The data rate shall be flexible and shall have a maximum rate of 256 K baud. The rate shall be selectable under software control. The exact format for the serial digital interface is unspecified; however, the use of the EIA Standard RS-232C and the use of ARINC Spec 419 and ARINC 561-2 are encouraged as references.

Careful consideration shall be given to the design of the serial digital interface to prevent a single element failure from introducing spurious signals and inducing failures in other elements.

3.6.4 Parallel digital interface.-PCAAS shall have provision for a parallel digital interface in which words are transmitted in bit parallel, word serial format to permit parallel data exchange between peripheral elements and the MCC as well as intra MCC data exchanges including Direct Memory Access (DMA). The data rate shall be flexible and shall have a maximum burst rate capability of 256 K baud.

The exact format for the parallel digital interface is unspecified. However, the use of IEEE 488 is encouraged as a reference.

Careful consideration shall be given to the design of the parallel digital interface to prevent a single element failure from introducing spuriout signals or inducing failures in other elements.

3.6.5 Fail operational interface.-The PCAAS system design shall give consideration to permit continued operation upon the failure of any element. Specifically the MCC shall be designed such that if any CPU fails another CPU can assume the critical tasks of the failed CPU as well as assume control over the failed CPU's I/O elements.

4.0 TEST REQUIREMENTS

4.1 Functional Failure Detection and Annunciation

PCAAS shall provide built-in test equipment (BITE) to detect functional failure and to annunciate such failures in an unambiguous fashion on the control panel.

4.2 LRU Fault Isolation

The PCAAS BITE together with diagnostic tapes shall be capable of isolating a failed LRU in the aircraft. In the event the LRU interface is such that isolation to a single LRU is not possible, then such isolation shall be to two LRU's.

4.3 SRU Fault Isolation

The PCAAS BITE together with diagnostic tapes loaded into the MCC shall be capable of isolating a failed SRU in a bad LRU to a single SRU; or if not possible, to two SRU's.

4.4 Functional Test

PCAAS shall provide automated functional test capability by loading a functional test tape into the MCC during preflight to check for operational status of all PCAAS functions and modes to a confidence level of 90 percent.

4.5 Performance Test

PCAAS shall provide automated performance test capability by loading a performance test tape into the MCC during a system calibration flight. Such tests shall check all significant system level performance parameters including NAV accuracy, display readability, fuel reserve computations, and other critical parameters.

5.0 COMPONENT TECHNOLOGY LEVELS

5.1 Alphanumeric Displays

The PCAAS alphanumeric displays shall utilize recent LCD technology. LED and gas discharge displays shall not be used except for special cases because of excessive power drains and difficulty of viewing at 10,000 ft-lamberts cockpit illumination.

5.2 Flat Surface Displays

Magnetically focused, fixed yoke CRT displays operated in a TV format shall be used for flat surface displays. Other technology such as LCD displays for flat surface shall not be used because of the primitive stage of development.

5.3 Keys and Switches

The use of multiple projected legend switches shall be used to conserve panel space.

PCAAS shall use Hall effect switch elements to the extent possible because of the potential reliability improvement over mechanical switches.

5.4 Microcircuits

The use of CMOS technology is encouraged for integrated circuits where speed requirements on the logic permit. Otherwise Schottky bipolar logic shall be used.

Microprocessor technology shall either utilize NMOS or PMOS for implementing the CPU and selected memory elements. The use of Ion implant to enhance the performance of the NMOS or PMOS chips is encouraged.

Nonvolatile RAM requirements may be implemented using either CMOS with a battery or MNOS (Metal Nitride Oxide semiconductor).

The MCC program memory shall use fused ROM for common subroutine or macro. instructions. The executive routines shall be implemented using Erasable ROM's to permit ease of program modification during flight test.

5.5 Inertial Instruments

Consideration shall be given to the use of strapdown inertial instruments utilizing MCC coordinate transformations as a potential low-cost attitude and heading reference unit (AHRU).

5.6 Engine Instruments

PCAAS shall consider the use of silicon based transducer elements for engine instruments with MCC processing for linearity and scale factor calibration. The instrument values shall be displayed on LCD "thermometer" displays.

5.7 Air Data Instruments

PCAAS shall consider the use of silicon based transducer elements for air data instruments. The use of vertical acceleration mixing with the rate of climb signal shall be considered to provide IVSI capability. The MCC shall provide signal processing. LCD thermometer displays shall be utilized where practical.

5.8 AFCS Actuators

PCAAS shall utilize low-cost electric actuators where feasible. The AFCS actuators shall include digital to analog conversion in response to BCD or Gray code commands.

5.9 Antennas

PCAAS shall utilize integrated antennas when possible to save cost, weight, and improve functional performance. Breakthroughs in antenna technology are not anticipated. The use of stripline antenna technology is encouraged where feasible.

5.10 RF Circuits

PCAAS shall utilize redundant frequency synthesizers. Consideration shall be given to sharing frequency synthesizers provided fail operation requirements are not violated.

The COM/NAV radios shall eliminate unnecesary interface modules not required for the PCAAS digital interface. Such module elimination is anticipated to reduce current radio costs by a significant percentage.

5.11 Connectors

PCAAS shall use gold contact connectors with positive pressure locking to minimize the probability of failure due to poor contacts.

5.12 Printed Circuit Boards

PCAAS shall utilize single sided, single layer plated through PCB's to the extent possible. Multi-layer, double sided boards are discouraged. Mounting of panel switches and other electro-mechanical devices on PCB's is encouraged to reduce intra-box cabling and wiring.

5.13 Packaging Technology

The PCAAS uniquely designed LRU's shall utilize blind connectors for ease of mounting where possible.

The PCAAS LRU's shall be cooled by radiation and convective cooling. The use of fluid cooling is prohibited. Fin cooling shall be employed to the degree feasible. Blowers will be used only as a last resort.

5.14 Mass Data Entry and Storage

PCAAS shall be implemented using magnetic tape cartridge utilizing digital recording. Provision shall be made to replace the tape cassettes with bubble domain memories should BDM's become economically feasible as a replacement for tape cassettes.

5.15 System Technologies

PCAAS shall employ the use of Kalman and other optimal filtering techniques to the maximum degree feasible and beneficial.

PCAAS shall employ functional redundancy and cross correlation techniques to reduce mission failures and flight catastrophes.

APPENDIX C

NOMENCLATURE

ADF	Automatic (airborne) direction finder
AFCS	Automatic flight control system
ALT	Altitude
ATC	Air traffic control
ATCRBS	Air traffic control radar beacon system
ATSD	Air traffic situation display
BC	Broadcast
BCAS	Beacon collision avoidance system
BDM	Bubble domain memory
BITE	Built-in test equipment
CAT	Category (for precision instrument approaches)
CHT	Cylinder head temperature
CMD	Command
CPU	Central processing unit
CS	Communications subsystem
CWS	Control wheel steering
DABS	Discrete address beacon system
DDBS	Digital data broadcast system
DG	Directional gyro
DMA	Direct memory access
DME	Distance measuring equipment
EAROM	Electrically alterable read only memory
EGT	Exhaust gas temperature

EHSS	Engine health subsystem
ELT	Emergency locator transmitter
EPROM	Erasable programmable read only memory
ETA	Estimated time of arrival
ETE/ETER	Estimated time en route
FAA	Federal Aviation Administration
FMS	Flight management subsystem
FPM	Feet per minute
FSCS	Flight status correlation subsystem
FSD	Flight situation display
GS	Glide slope
GPWS	Ground proximity warning system
HOL	Higher order language
HSI	Horizontal situation indicator
IAS	Indicated airspeed
IDC	Integrated displays and controls
IDCC	Integrated data control center
IFR	Instrument flight rules
ILS	Instrument landing system
INS	Inertial navigation system
IPC	Intermittent positive control
IVSI	Instantaneous vertical speed indicator
LAT	Latitude
LAX	Los Angeles International Airport
LF	Low frequency
LOC	Localizer

LNG	Longitude
LRU	Line replaceable unit
MCC	Microcomputer control complex
MCCSS	MCC subsystem
MEA	Minimum en route altitude
MLS	Microwave landing system
MTBF	Mean-time before failure
MTTR	Mean-time to repair
NDB	Nondirectional beacon
N&PFS	Navigation and position fixing subsystem
N mi	Nautical mile
NMD	Navigation Map Display
OMEGA	Extremely low frequency (10-13 KHz) worldwide navigation system
PCAAS	Preliminary Candidate Advanced Avionics System
PPI	Programmable peripheral interface
PROM	Programmable read only memory
RAM	Random access memory
RPM/rpm	Revolutions per minute
ROM	Read only memory
RMI	Radio magnetic indicator
RNAV	Area navigation
SFO	San Francisco International Airport
SID	Standard instrument departure route
SRU	Shop replaceable unit
SS	Surveillance subsystem
STAR	Standard terminal arrival route

TAS	True airspeed
TSO	Technical standard order
UG3RD	Upgraded third generation ATC system
UHF	Ultra high frequency (300-3000 M Hz)
VFR	Visual flight rules
VHF	Very high frequency (30-300 M Hz)
VLF	Very low frequency (3-30 M Hz)
VNAV	3D area navigation (includes vertical navigation)
VOR	VHF omnidirectional range
VORTAC	Co-located VOR and TACAN stations
WX	Weather

REFERENCES

1. Korell, D. D., and D. F. Schmidt, CRT Displays for Business Aircraft, SAE Paper No. 700210, Mar. 1970.

2. Guidance and Control Displays, AGARD Conference Proc. No. 96, Feb. 1972.

3. Jex, Henry R., R. Wade Allen, and Raymond E. Magdaleno, Display Format Effects on Precision Tracking Performance, Describing Functions, and Remnant, AMRL-TR-71-63, Aug. 1971.

4. Moir, G. D., and L. G. Innes, A Comparison of Six Vertical Speed Indicator Presentations, Royal Canadian Air Force, Inst. of Aviation Medicine, Rept. 63-RD-5, Dec. 1963.

5. Automotive Electronics II, SAE SP-393, Feb. 1975.